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DMIC Report 165
December 28, 1961

METHODS OF EVALUATING WELDED JOINTS

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Battelle Memorial Institute
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1. To collect, store, and disseminate technical information on the current status of research and development of the above materials.

2. To supplement established Service activities in providing technical advisory services to producers, melters, and fabricators of the above materials, and to designers and fabricators of military equipment containing these materials.

3. To assist the Government agencies and their contractors in developing technical data required for preparation of specifications for the above materials.

4. On assignment, to conduct surveys, or laboratory research investigations, mainly of a short-range nature, as required, to ascertain causes of troubles encountered by fabricators, or to fill minor gaps in established research programs.

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METHODS OF EVALUATING WELDED JOINTS

by

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to

OFFICE OF THE DIRECTOR OF DEFENSE
RESEARCH AND ENGINEERING

DEFENSE METALS INFORMATION CENTER
Battelle Memorial Institute
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METHODS OF EVALUATING WELDED JOINTS

SUMMARY

Methods of evaluating welded joints vary throughout the country, depending on the purpose of the evaluation, the welding process, material and thickness involved, and on the needs of the particular industry conducting the evaluation. These varying requirements have led to the development of many different test specimens. Recent introduction of new materials and joining processes has led to a sharp increase in the number of specimen types. This increase in turn has led to some confusion in the interpretation of results obtained by various organizations. The more widespread use of welding makes it imperative that this confusion be minimized so that exchange of data can be facilitated.

This report has been prepared to assist in accomplishing this objective. An analysis of existing specimens is included to show why so many different specimens are used, and the advantages and limitations of each specimen type. The analysis is a composite of available information in the literature, the engineering judgment and experience of the authors, and the results of two industry surveys.

The Defense Metals Information Center, in conjunction with the Aerospace Research and Testing Committee (ARTC) of the Aerospace Industries Association, surveyed a cross section of the welding industry to determine the types of test specimens used to evaluate weldments.

The data were obtained by the use of questionnaires. A total of 50 organizations representing Governmental agencies, shipyards, heavy fabricators, equipment manufacturers, research organizations, and universities were polled by DMIC. The AIA membership of 39 organizations was polled by the ARTC. Completed questionnaires were received from 32 organizations polled by DMIC and from 21 organizations polled by ARTC. Data were requested on 60 different test specimens in the ARTC survey. These 60, plus an additional 20 specimens, were included in the DMIC survey. Data requested included specimen dimensions, materials evaluated, purpose of test, nondestructive testing techniques used, important variables, type of data obtained, pertinent specifications, and availability of pertinent reports.

The results of this combined survey were as follows:

(1) Only a small percentage of the available weld test specimens are used extensively.

(2) For a given specimen, the same configuration and dimensions generally are used for all materials of comparable thickness.

(3) The same specimen shape and dimensions generally are used for testing at cryogenic, room, and elevated temperatures.

(4) The same specimens generally are used in developmental programs and to determine production quality, weldability, and design allowables.

(5) Generally, from two to six (with an average of three) specimens are tested for a specific condition.

(6) All common inspection methods (radiographic, penetrant, and magnetic in decreasing order of use), in addition to visual, are used to determine weld quality. Ultrasonic inspection is used to a very limited extent. Eddy current inspection was not used by any of the organizations responding.

(7) The important variables associated with weldment evaluation are specimen geometry, weld quality, weld inspection, measurements, and data analysis. Testing equipment and techniques sometimes are important in evaluating weldments with tests that are not standardized.

(8) Data on as many properties as possible are obtained from a given test.

Complete standardization of weld test specimens is extremely unlikely because of the varying requirements of different organizations. Still, considerably more specimen standardization is possible than now exists. Efforts should be directed toward this objective. Such an objective could be accomplished by an extensive program of correlating test data with service performance as well as by the correlation of similar data obtained from different specimens. Laboratory research programs should be initiated to supply much of the information regarding data correlation using various specimens. An investment in such a program ultimately should result in substantial savings by reducing duplication.

INTRODUCTION

The evaluation of welded joints has become an increasingly difficult task. Such evaluations are based on the use of test specimens which range from extremely small specimens that represent only a portion of a structure to a complete structural test. At best, any small-test specimens can reflect only the expected behavior in a structure in terms of a statistical average and of the accuracy with which the test conditions relate to the actual service conditions. This is true of any type of test specimen. With weld specimens, there are many additional complicating factors. There is considerable difference between evaluating a base material and welds in such a material. Most structures are largely base plate produced in quantity under carefully controlled and automated conditions. Welds are only a very small part of the structure and may be produced under conditions lacking control or automation.

Advances being made in welding techniques and technology have added to the difficulty of evaluating weldments. New processes, improved equipment, and a better understanding of the problems associated with welding have been developed in a relatively short period of time. As a result, welding has become a very efficient method for fabricating complex as well as simple assemblies. However, at the same time, many of the accepted weld test specimens are no longer suitable for use with the new materials and new processes. Quite naturally, this has led to a substantial increase in the types of specimens being used.

Designers and production people have always been faced with weldment evaluation. Designers are primarily interested in the allowable stresses for a given weldment. Production people are more concerned with weldability and quality control. Each group, over the years, has developed various weld test specimens to meet their particular needs. New specimens emerge regularly to add to the already voluminous list. As a result, there is little specimen standardization. Intercompany data comparison is difficult. Duplication of effort is large.

Before any attempt to standardize weld test specimens can be made, it is necessary first to determine the types of specimens that are needed to meet the multipurpose objectives of industry. An indication of such needs can be estimated from specimen usage. To supply this information, the Defense Metals Information Center surveyed a cross section of organizations concerned with welding. The Aerospace Research and Testing Committee (ARTC) of the Aerospace Industries Association (AIA) conducted a similar survey of their member companies as Project 28-58, "Standardization of Welded Joint Specimens". It was decided to combine the efforts of ARTC and DMIC and enlarge the scope of materials and organizations to be covered. The combined objectives were as follows:

(1) Include all metals in all thicknesses

(2) Consider only fusion-welded test specimens

(3) ARTC to survey only members of the AIA

(4) DMIC to survey a cross section of industry and Government agencies excluding AIA members

(5) The combined data to be reported by each organization according to their own interests.

This report summarizes the techniques used to obtain the information, the results of the surveys, and a discussion of the results. For those interested only in the overall results of the surveys, the section entitled "Results of Surveys" should be adequate.

The section entitled "Types of Test Specimens" discusses the important considerations of each of the various types of tests; i.e., tension, shear, bend, impact, etc. The significance and objectives of these tests, general as well as specific, are discussed. Specific data sheets for individual test specimens are included in this section. Pertinent data include line drawings, dimensions, materials evaluated, purposes of test, number of specimens tested, nondestructive inspection used, important test variables, data obtained, specifications, references, and remarks. Some specimen recommendations are made; however, test specimen standardization, per se, is not an immediate objective of this report.

SURVEYING TECHNIQUES

The data in this report were obtained by the use of questionnaires. A single questionnaire was used by the ARTC. Two questionnaires were used for the DMIC survey. Questionnaire No. 1 was used to determine the general types of tests used. The replies to this first questionnaire were used to customize the more comprehensive Questionnaire No. 2. For example, an organization that indicated the use of unnotched tension tests for flat sheet in Questionnaire No. 1 received data sheets for four different specimens of this type in Questionnaire No. 2. However, organizations that failed to return Questionnaire No. 1 were sent the complete set of 80 specimens of Questionnaire No. 2. Questionnaire No. 1 and a typical sample sheet of Questionnaire No. 2 are in Appendix A, Tables A-1 and A-2.

Organizations surveyed by DMIC were selected as representative of the welding industry. Fifty organizations including Government agencies, shipyards, heavy fabricators, welding equipment manufacturers, research organizations, and universities were polled initially by DMIC. The AIA membership of 39 organizations was polled by the ARTC. These organizations are listed in Appendix A. The responses to these surveys are shown below.

		Response to Questionnaires			
		Questionnaire No. 1		Questionnaire No. 2	
By	Organization	Polled	Replied	Polled	Replied
DMIC	Governmental agencies	14	13	12	9
	Steel producers	6	4	5	4
	Shipyards	2	2	2	1
	Heavy fabricators	16	13	16	13
	Welding-equipment manufacturers	3	3	3	3
	Research organizations	4	4	3	1
	Universities	5	4	4	1
	Subtotals	50	43	45	32
ARTC	Aircraft manufacturers	--	--	39	21
	Grand Totals	50	43	84	53

The comprehensive Questionnaire No. 2 and the questionnaire used by the ARTC were similar. Sixty different test specimens were included in the ARTC questionnaire. All 60 of these specimens plus an additional 20 constituted a complete set for DMIC Questionnaire No. 2. Many types of specimens were excluded because of known limited use. However, blanks were supplied so that special specimens could be reported if desired. Data requested included specimen dimensions, materials evaluated, purpose of test, nondestructive testing techniques used, important variables, type of data obtained, pertinent specifications, and availability of pertinent reports. The results of these surveys are given in the next section.

RESULTS OF SURVEYS

The data from both the DMIC and the ARTC surveys were tabulated. Fifty-five of the 80 test specimens listed were being used by at least one organization. An additional 22 specimens were suggested by one or more of the polled organizations. Data sheets listing detailed information for 50 individual specimens are included in this report. These 50 specimens include: (1) all specimens (22) used by at least 10 per cent of the reporting organizations; (2) specimens (25) having limited use but considered important; and (3) additional specimens (three) not included in surveys. The data shown reflect, in most instances, the consensus of polled organizations.

The significant results of the combined surveys were as follows:

(1) Only a small percentage of the available weld test specimens are used by the surveyed organizations.

(2) For a given specimen, the same configuration and dimensions generally are used for all materials of comparable thickness.

(3) The same specimen shape and dimensions generally are used for testing at cryogenic, room, and elevated temperatures.

(4) The same specimens generally are used in developmental programs and to determine production quality, weldability, and design allowables.

(5) Generally, from two to six (with an average of three) specimens are tested for a specific condition.

(6) All common inspection methods (radiographic, penetrant, and magnetic in decreasing order of use) in addition to visual inspection are used to determine weld-specimen quality. Ultrasonic inspection is used to a very limited extent. Eddy-current inspection was not used by any of the participating organizations.

(7) The important variables in weldment evaluation are specimen geometry, weld quality, weld inspection, measurements, and data analysis. Testing equipment and techniques sometimes are important in evaluating weldments when nonstandardized tests are used.

(8) Data on as many properties as possible are obtained from a given test.

A summary of specimen usage is shown in Table 1, which lists only those specimens used by at least 1 of the 53 organizations reporting. It can be seen that only a small number of specimens were used extensively; this is illustrated in Figure 1. The most popular specimen was used by 91 per cent of the reporting organizations. However, only 50 per cent of the organizations used the 5 most popular specimens, and only 13 per cent of the organizations agreed on the use of 20 specimens. The variation in specimens with the type of test is shown in Figure 2. Tension, bend, impact, and crack-susceptibility tests predominate. Since the composite survey includes 21 aircraft companies covered by the ARTC inquiry, a somewhat different picture emerges when these aircraft companies are separated from the DMIC survey as shown in Figure 3. Still, the tension, bend, impact, and crack-susceptibility tests predominate. Note, however, the greater use of shear, fatigue, stress-rupture, and creep specimens, and the reduced use of impact, bend, and crack-susceptibility specimens by the aircraft companies. The use of a particular specimen depends on the types of materials tested and the nature of the fabricated products. For example, impact tests have never been used to so great an extent by aircraft companies as by steel producers. A logical explanation is that the aircraft companies use more face-centered cubic materials, such as aluminum and austenitic stainless steels, that do not exhibit notch-toughness transition behavior. Conversely, fatigue is of prime importance in aircraft design and is reflected in weld-test-specimen use. One of the principal reasons for the limited use of stress-rupture and creep test specimens is that the organizations most interested in very-high-temperature properties were not included in either the DMIC or ARTC surveys. For example, no aircraft-engine manufacturers were included. Other special-interest organizations probably would have altered the relative use of the various groups of specimens. A further breakdown of specimen use by types of organizations is shown in Table 2.

The effects of materials on specimen use are shown in tabular form in Table 3 and graphically in Figure 4. It should be noted that materials designations used in the AIA questionnaire differed slightly from those used in the DMIC questionnaire. For clarity, the types of materials are identified in each questionnaire below.

Material Types as Listed on Questionnaire		
DMIC Questionnaire	ARTC Questionnaire	Typical Types of Materials
Aluminum, magnesium and their alloys	Aluminum, magnesium and their alloys	
Titanium and titanium alloys	Titanium	
Plain-carbon steels	--	A-7, A-373
Low-alloy high-strength steels	---	T-1, NAX 90, HY-80
Ultrahigh-strength steels	Carbon and low alloy	SAE 1040, 4340, 300 M, Ladish 0-6, H-11
High-alloy steels	Corrosion resistant Semiaustenitic	Stainless steels Precipitation-hardening steels
	Super alloys	René 41, A-286
Refractory metals	Refractories	
Beryllium	Beryllium	

TABLE 1. SUMMARY OF SPECIMEN USE

		Organizations Using Specimen					
		DMIC Poll		ARTC Poll		Total	
Specimen	Name of Specimen	Number	Per Cent	Number	Per Cent	Number	Per Cent
1	Transverse-weld tension – flat	28	88	20	95	48	91
2	Transverse-weld tension – flat	4	13	3	14	7	13
3	Longitudinal-weld tension – flat	7	22	11	52	18	34
4	Longitudinal-weld tension – flat; all weld metal	1	3	3	14	4	8
5	Transverse-weld tension – round	15	47	7	33	22	42
7	All-weld-metal tension – round	19	59	13	62	32	60
8	Longitudinal tension – fillet shear	0	0	4	19	4	8
9	Longitudinal tension – fillet shear	1	3	0	0	1	2
10	Transverse tension – fillet shear	6	19	8	38	14	26
11	Transverse tension – fillet shear	2	6	6	29	8	15
14	Longitudinal tension – butt shear	0	0	2	10	2	4
15	Longitudinal weld, guided bend – face bend	16	50	7	33	23	43
16	Longitudinal weld, guided bend – root bend	11	34	6	29	17	32
17	Transverse weld, guided bend – face bend	24	75	12	57	36	68
18	Transverse weld, guided bend – root bend	21	66	11	52	32	60
19	Transverse weld – side bend	19	59	3	14	22	42
20	Longitudinal weld, free bend – face bend	3	9	3	14	6	11
21	Transverse weld, free bend – face bend	6	19	6	29	12	23
24	Notched, transverse weld, guided bend	0	0	1	5	1	2
25	Charpy vee-notched impact	20	63	7	33	27	51
27	Charpy keyhole-notched impact	3	9	--	--	3	6
30	Tension	1	3	1	5	2	4
31	Notched-tension impact	1	3	2	10	3	6
32	Drop-weight impact	4	13	--	--	4	8
33	Explosion-bulge impact	3	9	--	--	3	6
34	Army Ordnance Ballistic H-plate	3	9	--	--	3	6
35	Transverse weld, axial fatigue – round	1	3	2	10	3	6
36	Longitudinal weld, axial fatigue – flat	0	0	3	14	3	6
37	Longitudinal weld, axial fatigue – flat	0	0	2	10	2	4
39	Transverse weld, axial fatigue – flat	1	3	10	48	11	21
47	Axial fillet-weld fatigue	0	0	1	5	1	2
50	Plate bending fatigue	3	9	1	5	4	8
51	Constant-moment bending fatigue	0	0	3	14	3	6
53	Rotating-beam bending fatigue	5	16	1	5	6	11
54	Notched rotating-beam bending fatigue	1	3	1	5	2	4
55	Transverse weld, stress rupture – flat	3	9	8	38	11	21
56	Longitudinal weld, stress rupture – flat	1	3	0	0	1	2
57	Transverse weld, creep – flat	0	0	3	14	3	6
59	Crack susceptibility – Lehigh	3	9	0	0	3	6

TABLE 1. (Continued)

Specimen	Name of Specimen	Organizations Using Specimen					
		DMIC Poll		ARTC Poll		Total	
		Number	Per Cent	Number	Per Cent	Number	Per Cent
60	Crack susceptibility – Houldcroft	1	3	0	0	1	2
61	Crack susceptibility – circular patch	3	9	8	38	11	21
62	Crack susceptibility – modified circular restraint	4	13	1	5	5	9
63	Crack susceptibility – U.S. Navy "Torture" test	1	3	--	--	1	2
64	Crack susceptibility – U.S. Navy circular patch	4	13	--	--	4	8
65	Crack susceptibility – Naval Research Laboratory	2	6	0	0	2	4
68	Crack susceptibility – cruciform	10	31	2	10	12	23
69	Crack susceptibility –Alcoa "T"	4	13	0	0	4	8
71	Crack propagation – Naval Research Laboratory	3	9	--	--	3	6
72	Crack propagation – NASA	3	9	--	--	3	6
74	Longitudinal bead-weld notch-bend ductility – Kinzel	2	6	--	--	2	4
76	Fillet-weld tee-bend ductility	2	6	--	--	2	4
77	Nick-break-weld soundness	5	16	--	--	5	9
78	Fillet-weld soundness	10	31	--	--	10	19
79	Bead-on-plate weldability	9	28	--	--	9	17
80	Underbead cracking – longitudinal weld	5	16	--	--	5	9

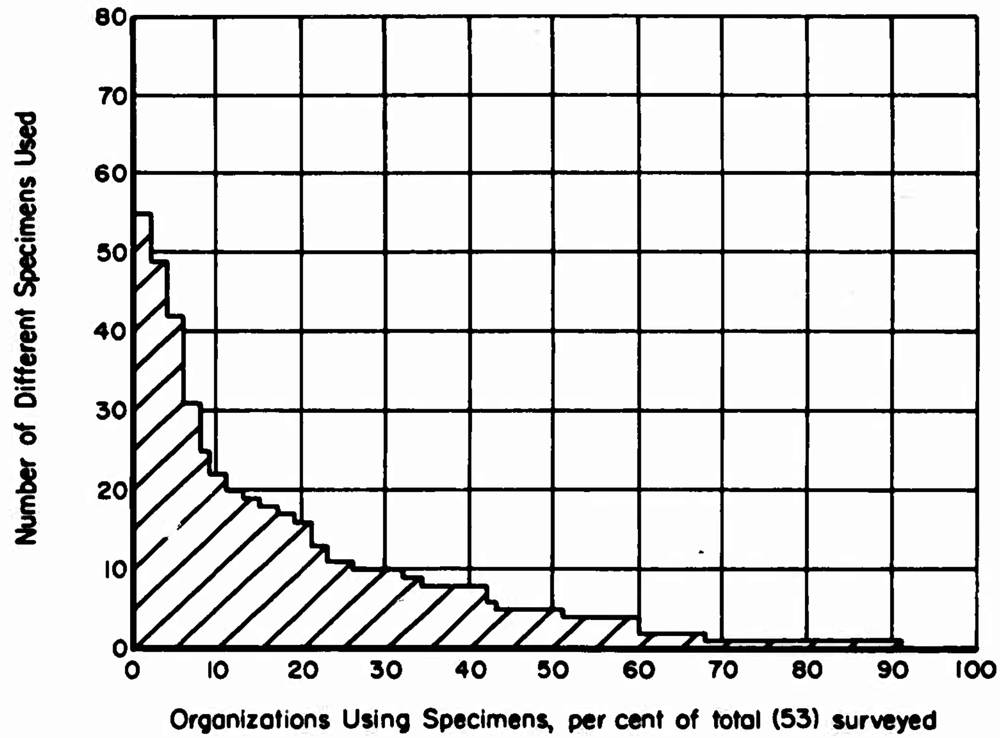


FIGURE 1. RELATION BETWEEN INDIVIDUAL SPECIMEN USAGE AND ORGANIZATIONS USING SPECIMENS

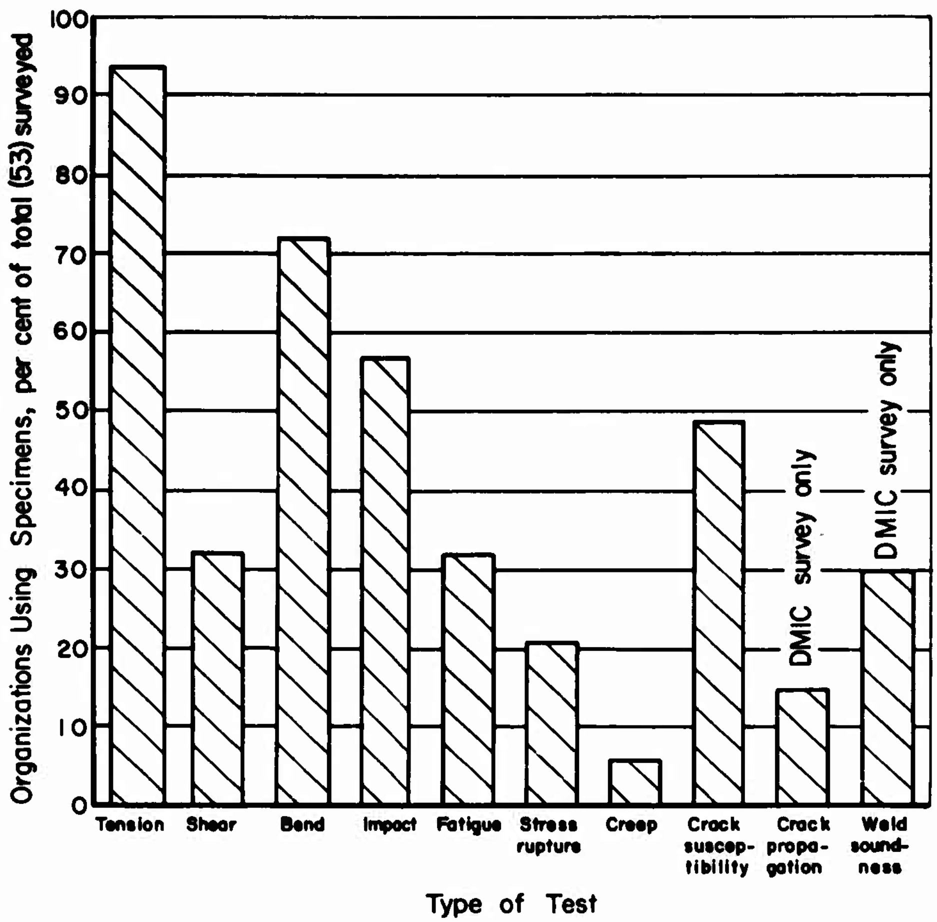


FIGURE 2. USE OF VARIOUS WELD TEST SPECIMENS BY TYPE OF TEST

Note: No crack-propagation or weld-soundness specimens included in ARTC survey.

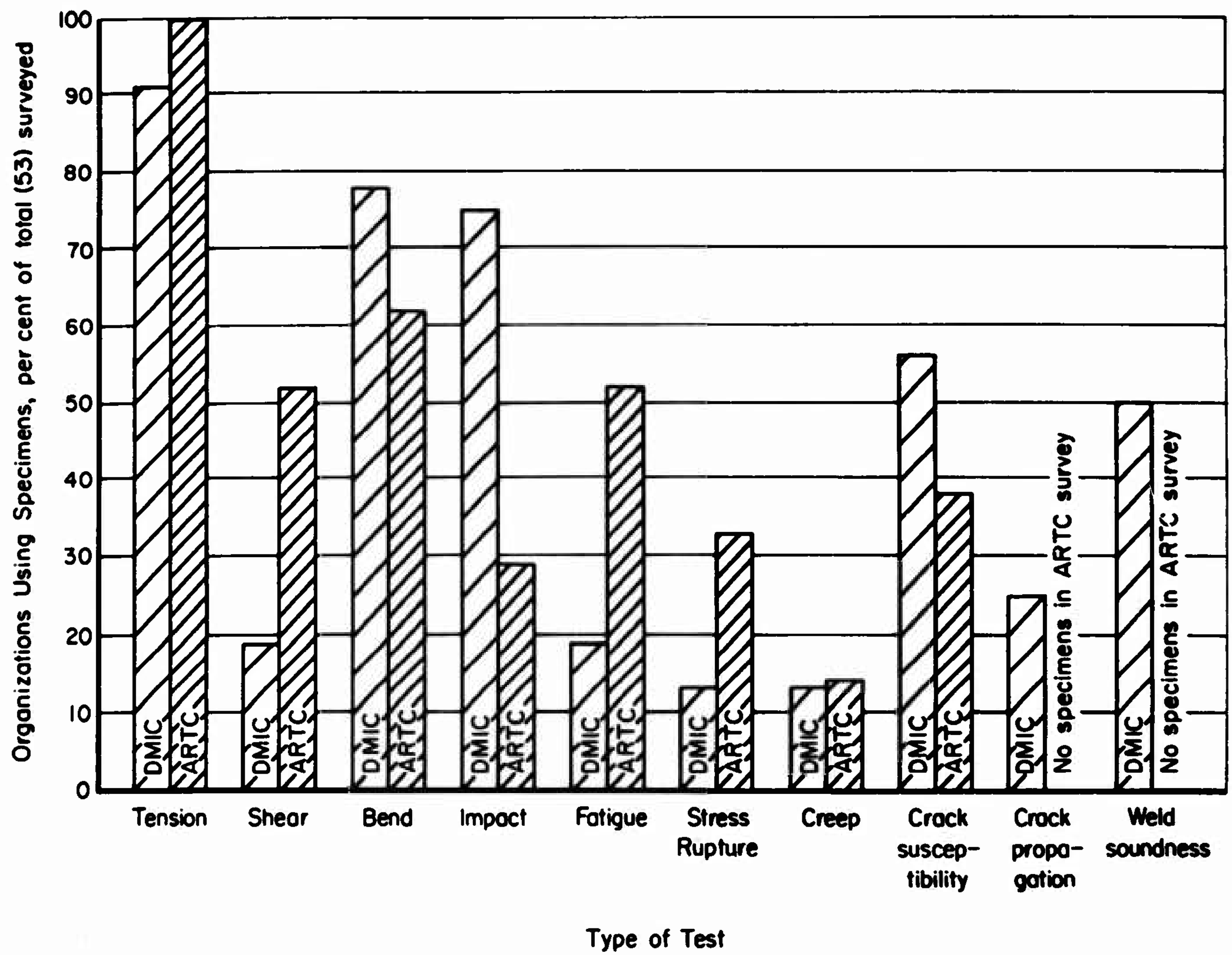


FIGURE 3. USE OF VARIOUS WELD TEST SPECIMENS BY TYPE OF TEST AND BY INDIVIDUAL SURVEY

TABLE 2. SUMMARY OF SPECIMEN USE BY TYPE OF ORGANIZATION

Type of Organization	Number of Organizations	Organizations Using Specimens, per cent of organizations surveyed									
		Tension	Shear	Bend	Impact	Fatigue	Stress Rupture	Creep	Crack Susceptibility	Crack Propagation	Soundness
Governmental agencies	9	89	22	56	78	22	11	0	67	33	56
Steel producers	4	100	0	75	75	50	25	0	50	0	50
Heavy fabricators	14	93	14	93	64	21	14	0	50	29	43
Welding-equipment manufacturers	3	100	67	100	100	0	0	0	67	0	33
Research organizations and universities	2	50	0	50	50	0	0	0	50	50	100
Aircraft companies	21	100	52	62	29	52	33	14	38	--	--

TABLE 3. SUMMARY OF SPECIMEN USE BY TYPE OF MATERIAL

Type of Material	Organizations Using Specimens, per cent of organizations surveyed										
	Tension	Shear	Bend	Impact	Fatigue	Stress Rupture	Creep	Crack Suscep-tibility	Crack Propaga-tion(a)	Sound-ness(a)	All Types of Specimens
Aluminum and magnesium alloys	70	19	49	19	13	8	4	9	9	16	74
Titanium and alloys	47	8	32	15	19	9	6	8	0	9	55
Plain-carbon steels	43	11	40	36	4	2	0	17	13	38	49
Low-alloy, high-strength steels	51	6	43	40	8	6	0	28	16	41	57
Ultrahigh-strength steels	74	17	47	34	19	9	4	32	4	22	79
High-alloy steels	76		59	38	26	19	6	28	13	25	85
Refractory metals and alloys	17	4	13	6	8	8	4	4	0	3	21
Beryllium	9	4	11	4	4	4	4	2	0	0	15

(a) Based on DMIC survey only since no specimens of these types were included in ARTC survey.

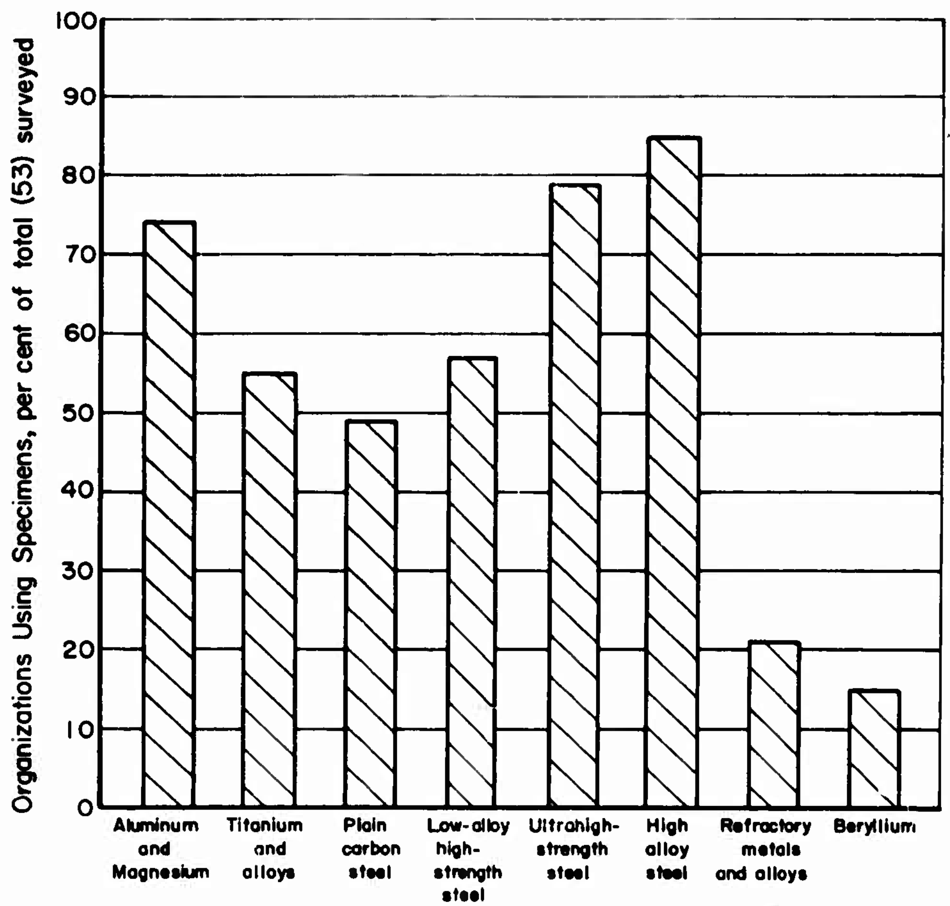


FIGURE 4. USE OF VARIOUS WELD TEST SPECIMENS ACCORDING TO MATERIALS

It should be noted that the ARTC questionnaire made no provisions for plain-carbon or low-alloy high-strength steels such as quenched and tempered steels below 120,000 psi tensile strength. However, the percentage of use of plain-carbon and low-alloy high-strength steels shown in Figure 4 was based on the total of 53 companies surveyed. Also, the ARTC questionnaire made separate provisions for the corrosion-resistant, semiaustenitic steels and the superalloys, which are combined with the high alloys in the DMIC questionnaire. Regardless, Figure 4 reflects the increasing interest in higher-strength steels – a trend that is expected to continue.

Although many organizations indicated that much of the information on mechanical testing and mechanical properties was covered in organization reports, very few organizations will release these data for publication. The proprietary nature of work by these organizations makes widespread data publication and data interchange unlikely.

TYPES OF TEST SPECIMENS

Specimen usage and general information regarding the results of the combined surveys were discussed in the previous section. A discussion of the various groups of test specimens follows. The specimens are identified by number, and data regarding these specimens can be found on corresponding data sheets. A line drawing showing configuration and pertinent dimensions is included for each specimen.

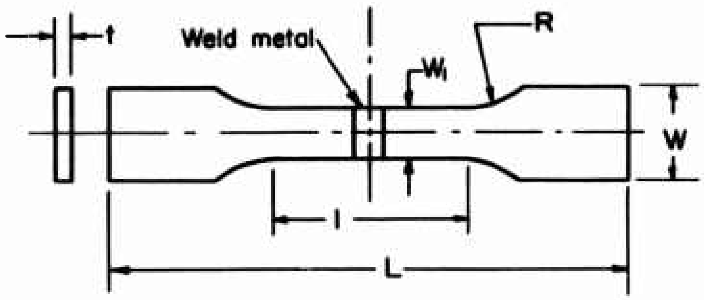
Tension

Uniaxial tension tests are used more than any other type. Of these, the transverse-weld specimens are heavily favored by the polled organizations. The transverse-weld, flat-sheet tension specimen (Specimen No. 1) was used by 89 per cent of these organizations as compared with only 34 per cent who used the longitudinal-weld, flat-sheet tension specimen (Specimen 3). The transverse-weld specimens provide a measure of joint efficiency, but do not provide a good measure of weld ductility. This is particularly true if the weld-metal strength considerably exceeds that of the base plate. In such a case, almost all of the plastic strain occurs in the unwelded base plate with resultant necking and failure outside of the weld area. Base-plate failure in this case provides no basis for evaluating weld strength and ductility. Where weld-metal strength is considerably lower than that of the base plate, almost all plastic strain occurs in the weld. The localization of strain in this case will reduce the elongation measured over the composite structure.

In the longitudinal-weld tension specimen (direction of loading parallel to the weld), all zones in the joints must strain equally and simultaneously. Weld metal, regardless of strength, elongates with the base plate until failure occurs. Poor weld-metal ductility often forces fracture initiation to occur at strength levels considerably below that of the surrounding unwelded base plate. On the other hand, weld metals with good ductility and appreciably lower strength than that of the base plate may sustain

SPECIMEN 1

TRANSVERSE-WELD TENSION SPECIMEN – FLAT



Dimensions, inches				
W	W_1	l	L	R
3/4	0.500 ± 0.010	2-1/4 min	8 min	1/2 min
2	1-1/2 ± 0.01	9 min	16±	1-3

Dimensions shown are ASTM standard for unwelded base plate: smaller specimen used for t from 0.005 to 5/8 inch; larger specimens used for t of 3/16 inch and over; used for all temperatures and all atmospheres; tested with and without weld reinforcement, preferably without.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, magnetic (where possible) and ultrasonic; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

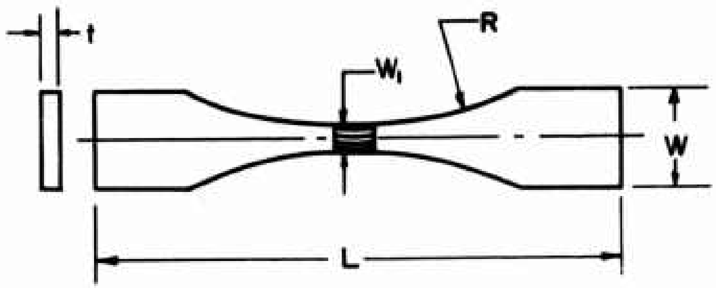
Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0.2 per cent offset but some use of 0.1 per cent offset; elongation in 2 inches most used but elongation in 1 inch and in 1/2 inch used occasionally; elongation in 8 inches used for larger specimen; reduction of area rarely determined for ultrahigh-strength steels.

Specifications - ASTM E8-57T covers tension testing of base materials but same specimen usually used for welds; MIL-STD-418 has specification for welded specimen but differs from ASTM.

Remarks - Most widely used test specimen; should be used in conjunction with longitudinal-weld tension specimen to obtain accurate evaluation of weldment strength and ductility (see text).

SPECIMEN 2

TRANSVERSE-WELD TENSION SPECIMEN - FLAT



Dimensions, inches				
t	W_1	W	L	R
0.050	0.20	1.50	9.34	3.00
1.00	1.00	1.50	10.00	2.00

Dimensions shown represent extremes with major dimensions about the same for intermediate values of t; usually tested at room temperature in air without weld reinforcement.

Materials Evaluated - All except refractory metals and beryllium.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, and magnetic (where possible); visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

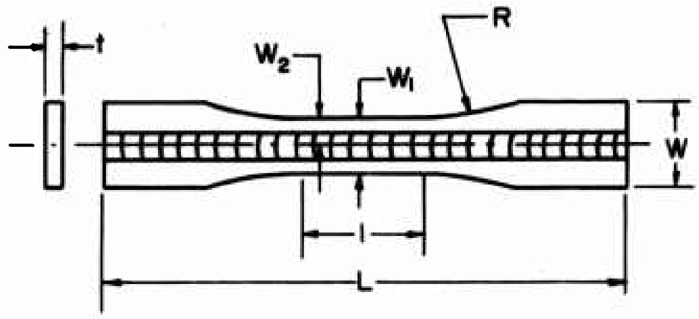
Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steel, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by 0.2 per cent offset-yield technique; elongation in 1/2, 1, and 2 inches determined.

Specifications - Usually company specifications.

Remarks - Should be used in conjunction with longitudinal-weld tension specimen to obtain accurate evaluation of weldment strength and ductility (see text).

SPECIMEN 3

LONGITUDINAL-WELD TENSION SPECIMEN – FLAT



Dimensions, inches						
W	W_1	W_2	l	L	t	R
3/4	1/2	1/4	2-1/4	8	t	1
1-1/2	1	1/2	4	12	t	2

Smaller dimensions used for t up to 1/4 inch; larger dimensions used for t greater than 1/4 inch; usually tested in air at 70 F but limited use at elevated temperatures; usually tested without weld reinforcement.

Materials Evaluated - All.

Purpose of Test - Developmental, strength, ductility, weldability, and design allowables; seldom used for production quality.

Number of Specimens Tested - Usually 3, varying from 2 to 4.

Nondestructive Inspection (in order of decreasing use) - Radiographic, magnetic (where possible), penetrant, and ultrasonic; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

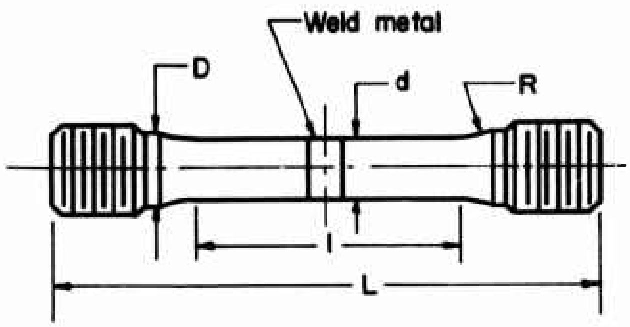
Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0.2 per cent offset but some use of 0.1 per cent offset; elongation in 2 inches most used but elongation in 1 inch and 1/2 inch used occasionally; reduction of area rarely obtained for ultrahigh-strength steels.

Specifications - ASTM E8-57T (base-plate specimen but used for welds).

Remarks - Used much less than transverse-weld tension specimen but considered very important for evaluation of composite weldment (weld, HAZ, and base plate) strength; should be used in conjunction with transverse-weld tension specimen to obtain accurate evaluation of weldment strength and ductility (see text).

SPECIMEN 5

TRANSVERSE-WELD TENSION SPECIMEN - ROUND



Dimensions, inches				
d	D	l	L	R
0.505	3/4	2-1/4	5-1/2	3/8
0.357	1/2	1-3/4	3-1/2	3/8
0.252	3/8	1-1/4	3	1/4
0.160	5/16	3/4	2	1/4
0.113	1/4	5/8	1-5/8	1/4

Dimensions shown are MIL-STD-418; usually tested at room temperature in air but has been used for elevated-temperature tests.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, and magnetic (where possible); visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

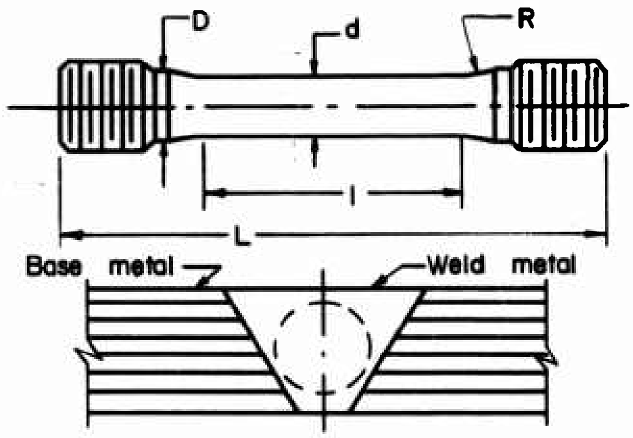
Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0.2 per cent offset with occasional use of 0.1 per cent offset; elongation in 2 inches most used but elongation in 1 inch and between the weld edges used occasionally.

Specifications - ASTM E8-57T, ASME Boiler Code Sec. IX and MIL-STD-418 cover round, all-weld-metal tension specimens; however, same specimens usually used for transverse-weld tests.

Remarks - Used extensively; should not be used as sole basis for weldment evaluation (see text).

SPECIMEN 7

ALL-WELD-METAL TENSION SPECIMEN – ROUND



Dimensions, inches				
d	D	l	L	R
0.505	3/4	2-1/4	5-1/2	3/8
0.357	1/2	1-3/4	3-1/2	3/8
0.252	3/8	1-1/4	3	1/4
0.160	5/16	3/4	2	1/4
0.113	1/4	5/8	1-5/8	1/4

Dimensions shown are MIL-STD-418; usually tested at room temperature in air.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, and magnetic (where possible); visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis; weld joint preparation such as type of backup bar used, root gap, and bevel are important variables as they influence the extent of dilution of the deposited filler metal with base metal.

Data Obtained - Tensile strength, yield strength, elongation, and reduction of area; for plain-carbon steels, both upper and lower yield strengths usually determined by drop-of-beam technique; otherwise, yield strength determined by offset-yield technique, usually 0.2 per cent offset with occasional use of 0.1 per cent offset; elongation in 2 inches most used but elongation in 1 inch used occasionally.

Specifications - ASTM E8-57T; MIL-STD-418; ASME Boiler Code Sec. IX.

Remarks - Second most widely used specimen; good specimen for accurate evaluation of weld-metal strength and ductility but base-plate dilution must be minimized for the specimen to be truly representative of all weld metal.

uniaxial loads to strength levels of the base plate. Because of these effects, weldment evaluation should include longitudinal-weld as well as transverse-weld specimens, particularly where the weld-metal and base-plate strengths differ.

Low-strength filler wires have been used for depositing girth or circumferential welds in rocket-motor cases fabricated from ultra high-strength steels. The hoop stress in the direction of the girth weld is about twice the stress across the weld. Longitudinal-weld tension tests would provide a reasonable basis for estimating the load-carrying capacity of the weldment. If only transverse-weld test specimens were used, it might be erroneously concluded that "undermatching" of filler wire was not feasible. For this application, the 2:1 stress biaxiality favors this approach as long as the weld-metal strength is sufficient to sustain the lesser longitudinal stresses.

The all-weld-metal tension specimens for round (Specimen 7) and for flat sheet (Specimen 4) permit accurate evaluation of weld-metal strength and ductility. However, base-plate dilution must be minimized if the specimen is to be truly representative of the weld metal. The flat sheet all-weld-metal specimen (No. 4) is more likely to suffer base-plate dilution effects.

Although most organizations used weld-tension tests of some kind, there is considerable variation in specimen dimensions. It is for this reason that strength and ductility data from various organizations are difficult to compare. Often, the reasons for variation in specimen dimensions are related to existing testing facilities, types and thicknesses of materials evaluated, and the purpose of testing, i. e., weldability or design allowables. However, within a given organization, the same basic specimen dimensions, such as width and gage length, generally are used for all materials. Standard flat-sheet tension specimens with 2-inch-gage lengths as specified by ASTM have a reduced-section gage length – specimen width ratio of 4 for specimens of thicknesses in the range 0.040 to 0.500 inch. For the 8-inch-gage length flat-sheet specimens used above 3/16 inch thick, this ratio is 5.3. For round specimens, as specified by ASTM and AWS, the gage length to specimen diameter ratio is maintained at 4. This minimum ratio is specified to provide sufficient length of reduced section for accurate elongation measurements across the necked-down fracture, since the elongation during necking occurs over a distance equal to two to three times the specimen diameter. The results of this survey showed that this ratio is generally used for round specimens. For flat-sheet specimens (No. 1), the gage length to specimen thickness ratio ranged from 1.3 to 9.0 with the average 4.3. A minimum ratio of 4 should be maintained.

It often becomes necessary to change the specimen cross-sectional area. Elongations of the various-size specimens can be compared directly, provided geometrical similitude is maintained. It has been determined that elongation is practically constant when the gage length, L, equals $k\sqrt{A}$, where A is the cross-sectional area of the specimen and k is a constant for the type of specimen. Strict adherence to this rule by all users would favor data comparison.

There was considerable variation among the organizations regarding the removal of weld reinforcement of flat tension specimens. About 60 per cent grind welds flush or surface grind the entire specimen before testing. In general, flush grinding of welds increases as higher strength materials are used. The effect of leaving weld reinforcement in place is twofold. First, the weld reinforcement lowers the net stress within the weld except at the weld edges. This stress reduction in the weld promotes unequal strain

in transverse-weld tension tests forcing most of the deformation to occur outside of the weld area. Second, the edge of the weld reinforcement will produce a stress concentration whose magnitude will depend principally on the abruptness and height of the edge of the weld reinforcement. Both of these factors tend to reduce over-all elongation and to localize strain at the edges of the weld. The choice of removing weld reinforcement will depend on whether service configuration is to be simulated. Flat-sheet testing of welds for developmental purposes usually is done without weld reinforcement.

Shear

Shear tests have had limited use by steel fabricators but are more widely used in the aircraft industries. A possible explanation for this limited use by steel fabricators is that weld shear stresses seldom control design. However, the aircraft industry makes extensive use of lap joints, many of which are spot welded. Fillet-weld shear strength and ductility for these applications often are critical.

Only the transverse tension-fillet shear specimens (Specimens 10 and 11) were used to any appreciable extent. Specimen 10 is the more desirable because of specimen symmetry. This specimen can be used for testing a wide range of fillet sizes without loss of specimen sensitivity. On the other hand, Specimen 11 is sensitive to plate thickness. The eccentric loading on this simple lap specimen increases with increasing plate thickness, introducing bending in addition to the shearing stresses. For this reason, Specimen 11 is used only with sheets not exceeding about 1/4-inch thickness.

The transverse tension-fillet shear specimens are sensitive to specimen preparation. Gaps between lapped plates magnify the stress-concentration effect at the root of the fillet weld joining the two faying surfaces. In addition, these specimens are sensitive to weld and heat-affected-zone (HAZ) defects such as weld undercut and underbead cracking. Unfilled weld craters at the ends of fillet welds can initiate failure, particularly with eccentric loading.

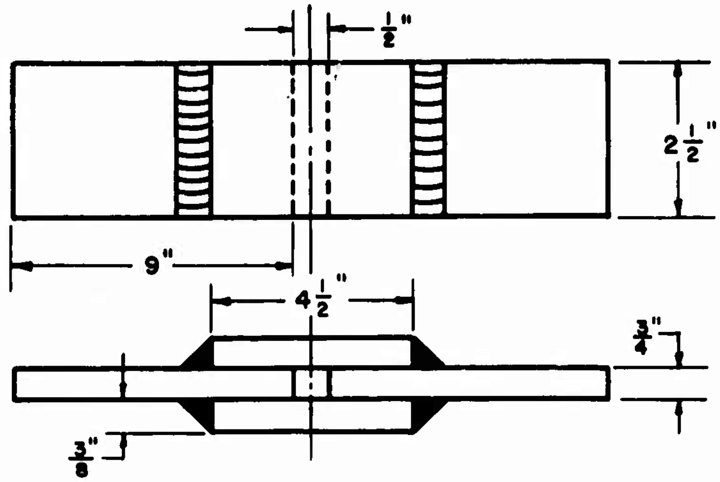
Torsion tests provide a more precise determination of shear properties for unwelded materials. Although torsion tests of welds were not included in this survey, they might reasonably be adapted for shear testing of welds. The torsion test might be particularly valuable for evaluating welds in ultrahigh-strength materials where ductility at best is low. In torsion loading, the shear stress is twice its value in tension. Use of shear torsion tests would amplify small changes in ductility as a result of processing, heat treatment, etc.

Bend

Bend tests were the second most widely used group of tests. Their popularity is justified. Bend tests are simple, economical both in use of materials and in specimen preparation, easily adapted for testing over a wide range of temperatures, and require only simple testing facilities; yet, they provide reliable evaluations of weld-joint ductility. All seven of the unnotched bend specimens included in the survey were used by at

SPECIMEN 10

TRANSVERSE TENSION-FILLET SHEAR SPECIMEN



Dimensions shown are MIL-STD-418; usually tested at room temperature in air.

Materials Evaluated - Principally aluminum, magnesium, and steels but has been used for titanium.

Purpose of Test - Developmental, production quality, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Nondestructive Inspection (in order of decreasing use) - Visual radiographic, magnetic (where possible), and penetrant; usually only visual inspection used.

Important Variables - Specimen geometry, weld quality, specimen positioning, strain-rate control, measurements, and data analysis.

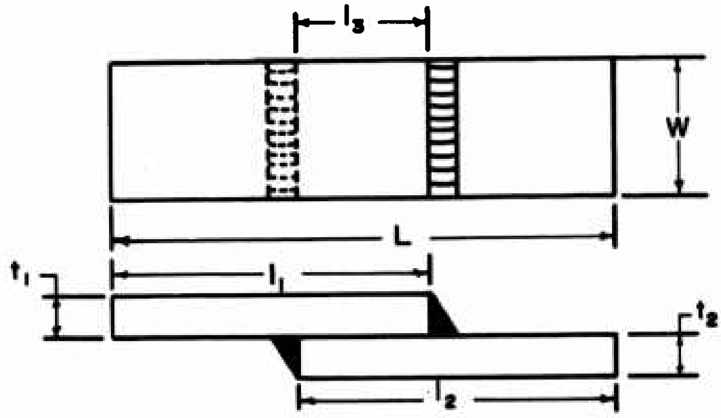
Data Obtained - Weld shearing strength (reported as pounds per lineal inch of weld).

Specifications - MIL-STD-418; API-12C.

Remarks - Most widely used shear specimen and considered most desirable; although dimensions shown above are standard, because of the absence of eccentric loading this specimen can be used for a wide range of plate thicknesses without loss of sensitivity; it is recommended that the specimen edges be machined to eliminate the effects of weld craters at ends.

SPECIMEN 11

TRANSVERSE TENSION-FILLET SHEAR SPECIMEN



Dimensions, in inches						
l_1	l_2	l_3	L	t_1	t_2	W
6	6	1-1/2	10-1/2	<1/4	<1/4	1-1/2
9	9	1-1/2	16	>1/4	>1/4	2

Dimensions varied widely; usually tested at room temperature in air.

Materials Evaluated - All.

Purpose of Test - Developmental, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, magnetic (where possible), and penetrant.

Important Variables - Specimen geometry, weld quality, specimen positioning, strain-rate control, measurements, and data analysis.

Data Obtained - Weld shearing strength (reported as pounds per lineal inch of weld).

Specifications - Usually company specifications.

Remarks - Since load eccentricity increases with increasing plate thickness, this specimen not usually used for plates greatly exceeding 1/4 inch thickness; it is recommended that the specimen edges be machined to eliminate the effects of weld craters at ends.

least 10 per cent of the organizations. The transverse-weld, guided-bend tests (Specimens 17 and 18) were used by 68 and 60 per cent of the polled organizations. However, the longitudinal-weld, guided-bend tests (face and root bend) are considered more useful for ductility evaluation for the same reasons given for the preference of longitudinal-weld tension tests, i. e. , compatible straining of weld, heat-affected zone, and base plate. Weld strength overmatching in transverse-weld, guided-bend specimens often prevents the weld zone from conforming exactly to the bend die radius with resultant overstraining of the heat-affected zones and base plate.

In general, the same specimen dimensions were used for transverse-weld and longitudinal-weld face, root, and side guided-bend specimens. Although specimen dimensions varied over a wide range, two sizes were preferred. For materials from 0.010 to 1/4 inch thick, specimen length and width usually were 6 and 1 inch, respectively. For materials over 1/4 inch thick, the length and width most often used were 10 and 1-1/2 inches. Free-bend specimens usually were slightly longer (about 12 inches) but about the same width (1-1/2 inches). The specimen length to width ratio for guided-bend specimens averaged about 6. However, AWS and military specifications for free-bend specimens permit this ratio to be decreased from 16.0 to 5.6 as plate thickness increases from 1/4 to 2-1/2 inches. The specimen length to width ratio is relatively unimportant for guided-bend tests since span length generally is much shorter than specimen length. The specimen width to thickness ratio is of considerably greater importance, since this ratio determines the extent of stress biaxiality produced during bending. This ratio varied from a low of 1.5 to a high of 18 but averaged about 6. In general, a specimen width to thickness ratio of at least 4 should be maintained.

Only guided-bend and free-bend specimens were included in this survey. However, considerable use is made of other bend specimens involving one- and two-point loading over a fixed span length. Often, load-deflection curves are obtained from these tests to determine yield load, elongation, and total energy-to-fracture (area under load-deflection curve). The span length to specimen depth ratio is important for single-point loading. For span length (l) to specimen depth (t) ratios less than about 6 (depending on material), shearing stresses become significant and contribute substantially to deflection. When this ratio, l/t, exceeds 6 by a considerable amount, bending stresses control. In general, an l/t ratio of at least 10 should be maintained for single-point loading. However, the two-point, symmetrical loading, "pure bending" system eliminates the effects of shear between the loading points so that fiber elongations are proportional to the distance from the neutral axis of the specimen in the elastic region and approximately so in the plastic region. For this reason, two-point loading is desirable, particularly for transverse weld-bend tests. In this instance, weld heat-affected zone and base plate are stressed equally in the constant-moment, central section of the specimen.

The data obtained from bend tests by various organizations differ. Elongation occurring in the outer fibers is determined by the use of gage marks placed on the specimens prior to bending or may be approximated by:

$$e = \frac{T}{2R + T} \times 100$$

where

e = elongation in outer fibers, per cent

T = plate thickness, inches

R = radius at inside surface of bend (bend die radius), inches.

In calculating bend elongation, the bend radius obtained just before failure is recorded. For tests where bend specimens are progressively bent over a series of decreasing radii dies, the last die passed before failure is recorded as the bend radius. In these tests, the specimen is "bottomed" in a vee block by each of the various dies in turn.

Bend ductility often is expressed in terms of the angle of bend just prior to failure. In this case, the bend angle must be interpreted under the specific conditions of the test. However, ductility expressed in terms of elongation, measured or calculated, is considered more reliable.

In general, the results of tests on unnotched bend specimens of low- and medium-strength steels are not greatly affected by changes in strain rate up to rates approaching impact. However, at very high strength levels (above 200,000 psi), strain-rate sensitivity often becomes very important. Strain-rate sensitivity also is very important in tests of many refractory-metal alloys.

Impact

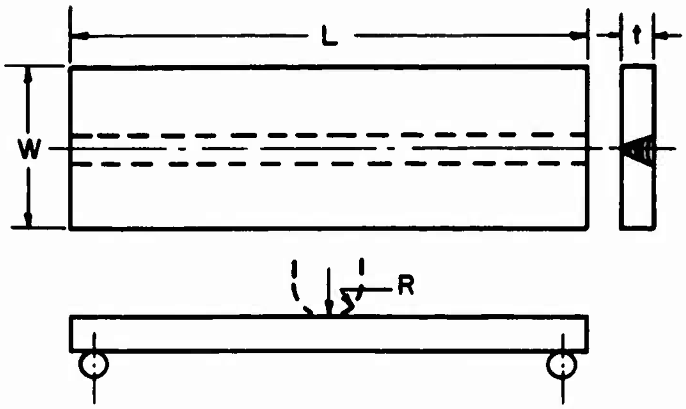
Impact tests were the third most widely used group of tests included in this survey. Of the 10 types of impact specimens included, only the Charpy Vee-notched impact specimen (Specimen 25) was used to any appreciable extent. As mentioned previously, there was considerable difference in the extent of use of impact specimens by aircraft companies included in the ARTC survey as compared with those organizations included in the DMIC survey. The somewhat limited use of impact specimens by aircraft companies can be traced to several reasons. First, aircraft companies use fewer materials that are subject to transition behavior. Second, aircraft are generally not subjected to as much shock or impact loading as the weldments produced by the organizations included in the DMIC survey.

Impact tests are used to measure the toughness of a material, that is, its ability to absorb energy without failure. This energy may be absorbed either through elastic deformation of the parts, through plastic deformation, or through effects of inertia of moving parts. Since, the ability of the material to absorb load varies considerably with the rate of loading, the relative toughness obtained under static and under impact loading would be expected to differ significantly. Such is the case with most materials. Notched and unnotched impact specimens have been used to measure toughness. In the former case, the toughness is referred to as notch toughness and is defined as the ability of the material to absorb energy in the presence of a discontinuity, such as a notch, crack, void, or other physical or metallurgical discontinuity.

Originally, impact tests were conceived to determine the ability of a fabricated part to absorb loading under severe service conditions. For this reason, most of the

SPECIMENS 15 AND 16

LONGITUDINAL-WELD, GUIDED-BEND SPECIMEN - FACE AND ROOT BEND



Dimensions, inches			
L	W	t	R
10	1-1/2	3/8	3/4
4	1-1/2	<1/4	Var.

Dimensions varied greatly, first dimensions shown are AWS standard. Second dimensions used for sheet with series of varying radii dies (see below); usually tested at room temperature in air with welds ground flush.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation.

Number of Specimens Tested - Usually 3, varying from 2 to 6.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, penetrant, magnetic (where possible), and ultrasonic.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, measurements, and data analysis.

Data Obtained - Elongation in outer fibers (either measured or calculated), angle of bend, minimum bend die radius, and load-deflection curves.

Specifications - AWS, MIL-STD-418 and ASME Sec. IX cover transverse-weld, guided-bend specimens but same dimensions usually used for longitudinal-weld test.

Remarks - Considered one of most valuable tests; when used as a 180-degree, guided-bend test, this is a go-no go test; however, if load-deflection, angle of bend, and minimum bend radius are determined, the test can be a quantitative test.

Testing Procedures:

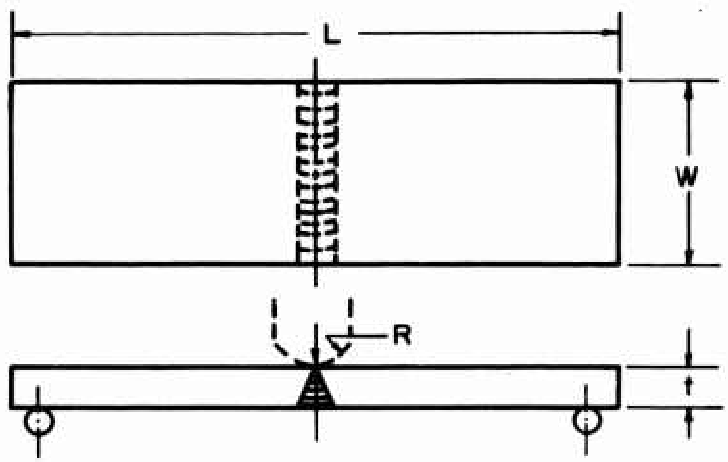
Standard guided bend - specimen bent about fixed radius until failure occurs or until specimen is bent 180 degrees. Surface defects on tension face must conform to allowable limits of pertinent specifications.

Single-point loading - load-deflection curve obtained for yield and ultimate strength and total energy-to-failure determinations. Also, angle of bend-to-failure can be reported but not considered as significant as elongation estimates.

Varying radii dies - specimen is bent over a series of varying radii dies until failure occurs. The specimen is "bottomed" in a vee block by each die. The last die passed before failure is recorded for elongation calculations (see text).

SPECIMENS 17 AND 18

TRANSVERSE-WELD, GUIDED-BEND SPECIMEN - FACE AND ROOT BEND



Dimensions, inches			
L	W	t	R
10	1-1/2	3/8	3/4
4	1-1/2	<1/4	Var.

Dimensions varied greatly. First set of dimensions shown are AWS standard. Second set of dimensions used for sheet with series of varying radii dies. Usually tested at room temperature in air with welds ground flush.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation.

Number of Specimens Tested - Usually 3, varying from 1 to 6.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, penetrant, magnetic (where possible), and ultrasonic.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, measurements, and data analysis.

Data Obtained - Elongation in outer fibers (either measured or calculated) across weld, angle of bend, minimum bend die radius, and load-deflection curves.

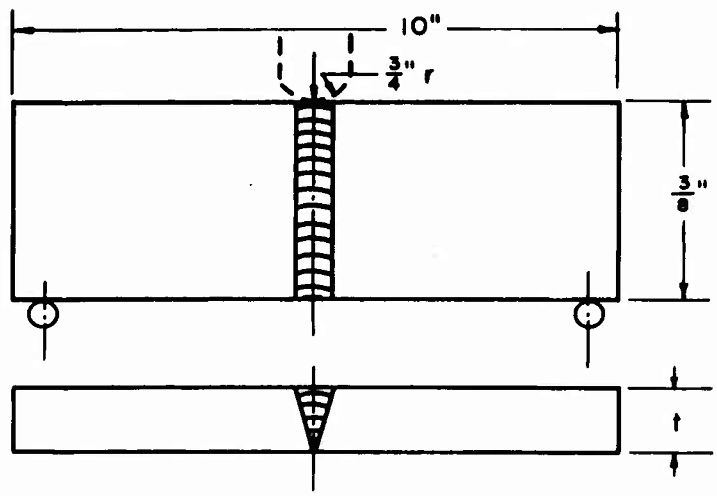
Specifications - AWS; MIL-STD-418; ASME Sec. IX.

Remarks - Sensitive to weld-metal strength and ductility; if weld-metal strength is greater than base plate and HAZ strength, almost all deformation will occur in base plate with weld area remaining virtually straight; if weld metal has same or lower strength than base plate, the weld area will conform to die radius and elongation measurements across weld will be reliable.

Testing Procedures - Same as for Specimens 15 and 16.

SPECIMEN 19

TRANSVERSE WELD, GUIDED-BEND SPECIMEN - SIDE BEND



For plates 3/4 to 1-1/2-inch thick, specimen t equals actual plate t (less any surface grinding); for plates over 1-1/2 inch thick, cut specimen into about equal strips 3/4 to 1-1/2 inch wide and test each strip; test not applicable to plates less than 3/4 inch thick. Usually tested at room temperature in air. Root and face of weld should be machined to prevent premature edge failure.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack-propagation and susceptibility, and weld soundness.

Number of Specimens Tested - Usually 3, varying from 1 to 6.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, penetrant, and magnetic (where possible).

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, measurements, and data analysis.

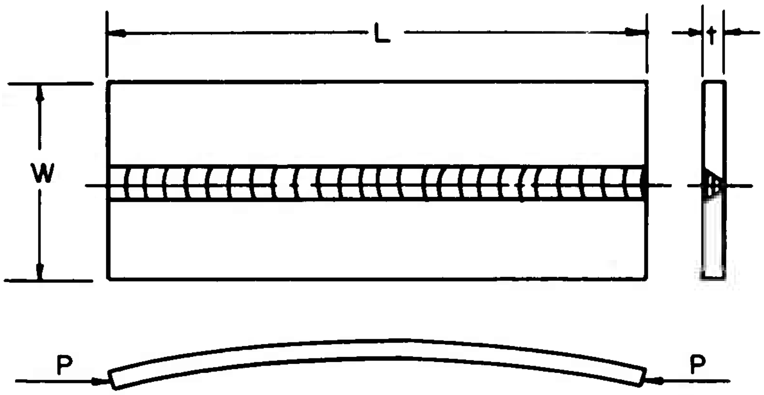
Data Obtained - Elongation in outer fibers (either measured or calculated) across weld, angle of bend, minimum bend, die radius, and load-deflection curves.

Specifications - AWS; MIL-STD-418; ASME Sec. IX.

Remarks - Side bending strains entire weld cross section, thus exposing defects near midthickness that might not contribute to failure in face- or root-bend test. Particularly useful in exposing lack of fusion defects and weld and HAZ cracks in multipass welds. This specimen often used to determine fissuring in stainless steel weldments.

SPECIMEN 20

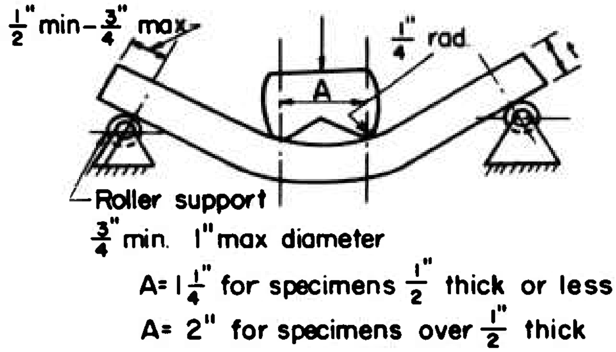
LONGITUDINAL-WELD, FREE-BEND SPECIMEN - FACE AND ROOT BEND



Dimensions, inches		
L	W	t
6	3/8	1/4
8	9/16	3/8
9	3/4	1/2
10	15/16	5/8
11	1-1/8	3/4
12	1-1/2	1
13-1/2	1-7/8	1-1/4
15	2-1/4	1-1/2
18	3	2
21	3-3/4	2-1/2

Dimensions shown are MIL-STD-418 for transverse-weld specimen. Usually tested in air at room temperature.

FINAL BEND FOR FREE-BEND SPECIMENS



INITIAL BEND FOR FREE-BEND SPECIMENS

Hardened and greased shoulder of same shape may be substituted for roller support.

SPECIMEN 20
(Continued)

Materials Evaluated - All except beryllium.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation, and weld soundness.

Number of Specimens Tested - Usually 2, varying from 1 to 3.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, magnetic particle (where possible), and penetrant.

Important Variables - Specimen geometry, weld quality, weld inspection, measurements, and data analysis.

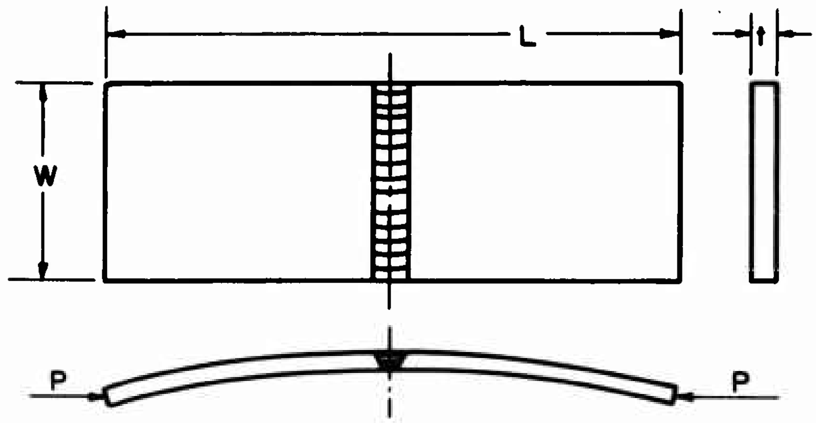
Data Obtained - Elongation in outer fibers (either measured or calculated), angle of bend, and minimum bend radius.

Specifications - None for longitudinal-weld specimen but specifications applying to transverse-weld specimen usually used.

Remarks - Only limited use made of this specimen. Although quantitative data such as elongation and angle of bend can be obtained, this test is principally a go - no go test. Surface defects on tension face must conform to allowable limits of pertinent specifications. A guided-bend test using varying radii dies or a single-point bending system used to obtain load-deflection curves generally is preferred to the free-bend specimens for quantitative evaluation.

SPECIMEN 21

TRANSVERSE-WELD, FREE-BEND SPECIMEN - FACE AND ROOT BEND



Dimensions, inches		
L	W	t
6	3/8	1/4
8	9/16	3/8
9	3/4	1/2
10	15/16	5/8
11	1-1/8	3/4
12	1-1/2	1
13-1/2	1-1/8	1-1/4
15	2-1/4	1-1/2
18	3	2
21	3-3/4	2-1/2

Dimensions shown are MIL-STD-418. Usually tested in air at room temperature.

Note: Initial bend for free-bend specimens same as for Specimen 20.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, ductility, weldability, design allowables, crack propagation, and weld soundness.

Number of Specimens Tested - Usually 2, varying from 1 to 6.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, magnetic particle (where possible), penetrant, and ultrasonic.

Important Variables - Specimen geometry, weld quality, weld inspection, measurements, and data analysis.

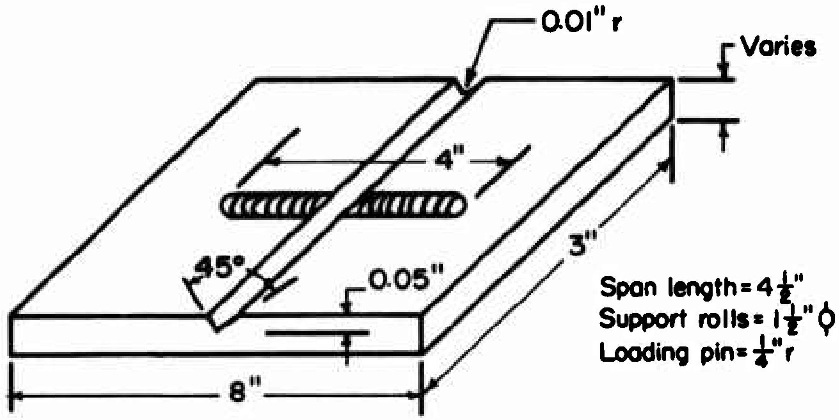
Data Obtained - Elongation in outer fibers (either measured or calculated), angle of bend, and minimum bend radius.

Specifications - AWS-ASME, ASTM E16-577, MIL-STD-418.

Remarks - Same as Specimen 20.

SPECIMEN 74

LONGITUDINAL-BEND-WELD NOTCH-BEND-DUCTILITY SPECIMEN – KINZEL



Dimensions as proposed by Kinzel; however, other dimensions have been used; span length and specimen length often varied; specimens usually welded without preheat and tested over range of temperatures to establish transition temperature.

Materials Evaluated - Plain-carbon and low-alloy, high-strength steels.

Number of Specimens – Usually 2 to 3 specimens if tests made at a single temperature; otherwise, sufficient specimens to test over a range of temperature to establish transition behavior.

Nondestructive Inspection - Visual and radiographic.

Important Variables - Specimen geometry, weld quality, specimen positioning, test-temperature control, measurements, and data analysis.

Data Obtained - Lateral contraction and fracture appearance usually determined; however, bend angle at maximum load and load-deflection curves have been used as performance criteria.

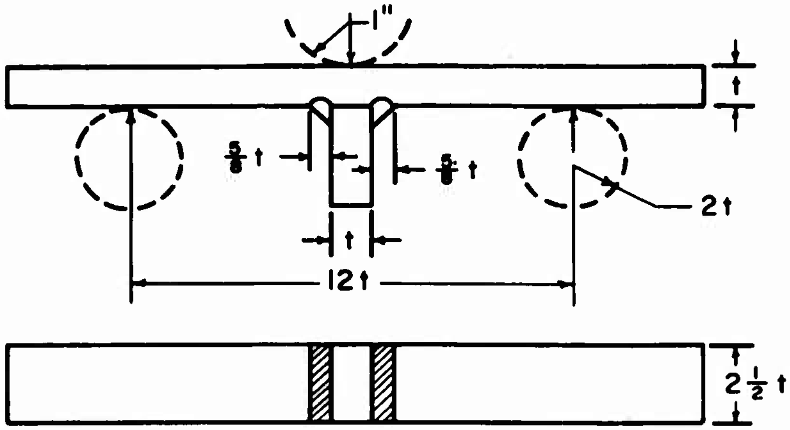
Specifications - None.

References - Kinzel, A. B., "Ductility of Steels for Welded Structures", Welding Journal, 27 (5), 217s (1948). Stout, R. D., and Doty, W. O., Weldability of Steels, Welding Research Council, 1953, pp 244-251.

Remarks - Specimen very useful for evaluating relative merits of steel compositions, heat treatment (before and after welding), and welding procedures; test is sensitive to HAZ and weld-metal changes as a result of heat input.

SPECIMEN 76

FILLET-WELD TEE-BEND DUCTILITY SPECIMEN



Usually used for t = 1/2 inch, but has been used for t = 1/4 to 1-1/2 inch; fillet weld deposited in a series of 18 increments, each about 2-11/16 inch long so as to form a joint 24 inches long containing 9 welded increments per side; after welding and aging a minimum of 21 days, bend specimens 2-1/2 t wide are cut from test specimens; usually tested at room temperature in air.

Materials Evaluated - Aluminum and aluminum alloys, plain-carbon, low-alloy high strength, ultrahigh-strength, and high-alloy steels.

Purpose of Test - Developmental, production quality, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 2.

Nondestructive Inspection (in order of decreasing use) - Visual, penetrant, and magnetic (wherever possible).

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, and data analysis.

Data Obtained - Absorbed energy (from load-deflection curve), angle of bend, lateral contraction at a point 1/32 inch below toe of fillet nearest failure, and fracture appearance.

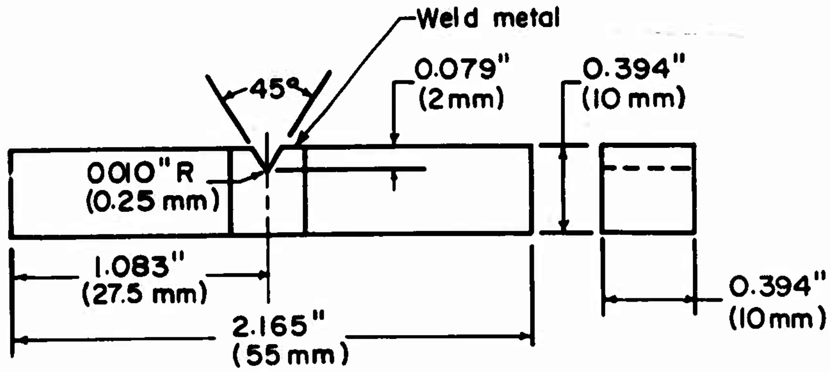
Specifications - AWS, MIL-STD-418.

References - Bibber, L. C., and Heuschkel, J., "Report of Tee-Bend Tests on Carbon-Manganese Steels", Welding Journal, 7 (10), 485s (1942). Bibber, L. C., and Heuschkel, J., "The Measurement of Energy Absorption in the Tee-Bend Test", Ibid., 9 (12), 609s (1944). Stout, R. D., and Doty, W. O., Weldability of Steel, Welding Research Council, p 258 (1953).

Remarks - Because of restrictions on fillet-weld size, this test is limited to a specific energy input for a given electrode size; necessarily, this limits usefulness of test for studying effects of welding-procedure changes.

SPECIMEN 25

CHARPY VEE-NOTCHED IMPACT SPECIMEN



Dimensions shown are ASTM standard; used for wide range of temperatures; usually tested in air.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, notch toughness, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3 if tested at only a single temperature; usually 2 per temperature for determination of transition temperature.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, magnetic (where possible), and ultrasonic; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, and data analysis.

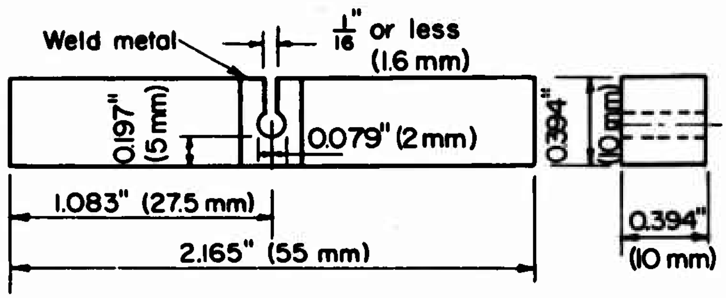
Data Obtained - Impact energy, lateral expansion and contraction, and fracture appearance.

Specifications - ASTM E-23; MIL-E-22200; Fed. Test Method Std. No. 151A221.1.

Remarks - Most widely used impact specimen. For base-plate evaluation, this specimen appears to be the best, partly because of the tremendous amount of data that have been collected using this specimen. The vee-notched specimen has practically replaced the keyhole-notched specimen (Specimen 27) in popularity.

SPECIMEN 27

CHARPY KEYHOLE-NOTCHED IMPACT SPECIMEN



Dimensions shown are ASTM standard; used for wide range of temperatures; normally tested in air.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, notch toughness, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3 if tested at only a single temperature; usually 2 per temperature for determination of transition temperature.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, and magnetic (where possible); visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, and data analysis.

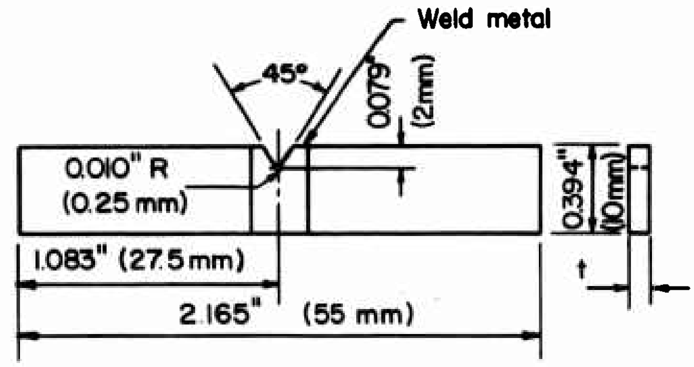
Data Obtained - Impact energy, lateral expansion and contraction, and fracture appearance.

Specifications - ASTM E-23.

Remarks - This specimen rapidly being replaced by vee-notched specimen (Specimen 25) in popularity. The Charpy keyhole specimen will give lower values of transition temperature than the vee-notched specimen for a given material.

SPECIMEN 29

SHEET CHARPY VEE-NOTCHED IMPACT SPECIMEN



Standard Charpy vee-notched specimen except specimen thickness, t, is equal to thickness of test sheet, t; used for wide range of temperatures; usually tested in air.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, notch toughness, ductility, weldability, design allowables, and fracture toughness (G_c).

Number of Specimens Tested - Usually 3 if tested at only a single temperature; usually 2 per temperature for determination of transition temperature.

Nondestructive Inspection (in order of decreasing use) - Data not available but probably same as for standard Charpy vee-notched specimen (Specimen 25).

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, and data analysis.

Data Obtained - Impact energy, lateral contraction, and fracture appearance; data have been obtained for fracture-toughness determinations as described below.

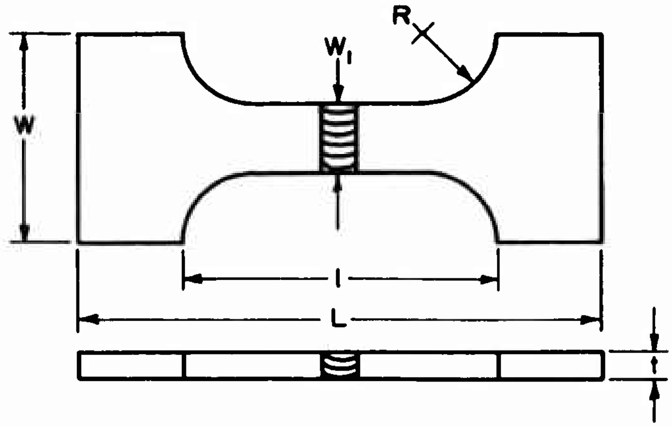
Specifications - ASTM-E-23 pertaining to full-size Charpy specimens would seem applicable.

References - Orner, G. M., and Hastbower, C. E., "Notch Sensitivity in High-Strength Sheet Materials", Welding Journal, 39 (4), 147s (1960). "Notch Sensitivity in High-Strength Sheet Materials", Reports of Progress, May 16 and September 30, 1960, Metals Joining Branch, Watertown Arsenal.

Remarks - Survey indicated very limited use for this specimen. However, it is believed that this specimen is very useful for evaluating sheet materials and will be used to a much greater extent in the near future. This specimen in modified form has been used successfully to determine fracture toughness (G_c). In the modified form, a controlled-depth fatigue crack is induced at the root of the notch by reversed bending. This produces a natural crack, thus eliminating the energy required to initiate fracture and the elastic-energy loss. Then, the specimen is fractured as in standard Charpy impact tests. The energy required to fracture the specimen divided by the fracture area (excluding the fatigue-cracked area) is a measure of the fracture toughness and correlates well with G_c values determined by center-notched fracture-toughness tests.

SPECIMEN 30

TENSION IMPACT SPECIMEN



Dimensions, inches					
l	L	W	W_1	t	R
1-1/8	7	11/16	.500	t	1
3.0	5.50	1.3	0.40	t	0.50

No specific dimensions given for t.
Tested over a range of temperatures from -40 F to 70 F in air.

Materials Evaluated - All except beryllium.

Purpose of Test - Developmental, notch toughness, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 2.

Nondestructive Testing (in order of decreasing use) - Radiographic, magnetic (where possible), and penetrant; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, strain-rate control, test-temperature control, measurements, and data analysis.

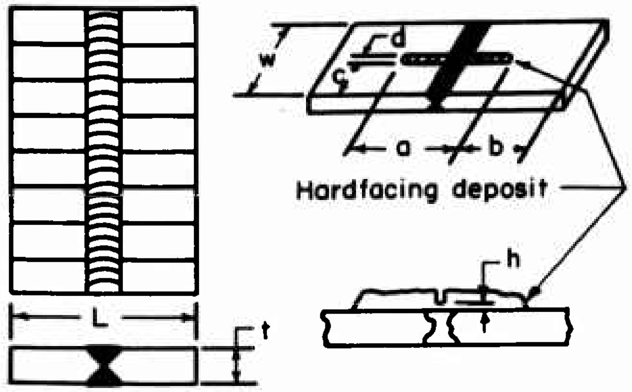
Data Obtained - Impact energy, fracture appearance, elongation in 1/2 inch and in 1 inch, and unnotched/notched stress ratio.

Specifications - Company specifications only.

Remarks - Very limited use; explosion-bulge and drop-weight impact tests believed to provide more reliable estimate of over-all weldment performance.

SPECIMEN 32

DROP-WEIGHT IMPACT SPECIMEN



Dimensions, inches							
L	W	t	a	b	c	d	h
14	3-1/2	1/2 to 1-1/4	2-1/2	5-3/4	1-1/2	1/2	1/16
5	2	1/2	2	1-1/2	3/4	1/2	1/16

NRL reference standard specimen is 14 by 3-1/2 by 1 inch with a 12-inch span and a 0.3-inch anvil stop. Smaller specimens used for materials thinner than 3/4 inch but at least 1/2 inch. Testing done over wide range of temperature in air.

Materials Evaluated - Plain-carbon, low-alloy high-strength, ultrahigh-strength, and high-alloy steels.

Purpose of Test - Developmental, ductility, crack susceptibility, crack propagation, impact energy, and weldability.

Number of Specimens Tested - 6.

Nondestructive Inspection (in order of decreasing use) - Radiographic and magnetic; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, data processing, and data analysis.

Data Obtained - Impact energy and fracture appearance.

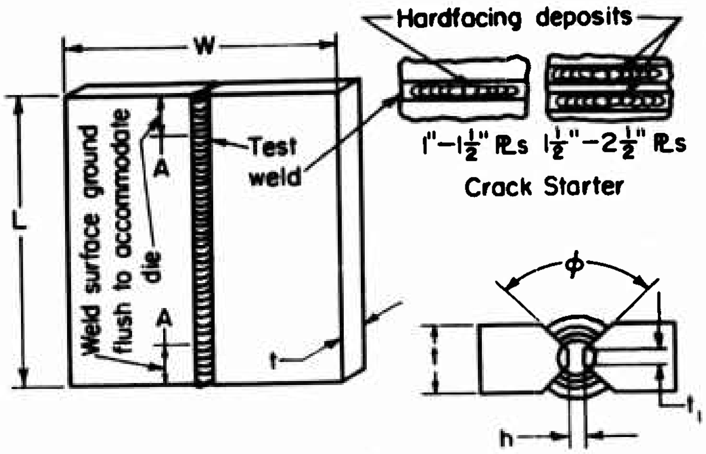
Specifications - See references.

References - Pellini, W. S., Puzak, P. P., and Eschbacker, E., "Procedures for N.R.L. Drop-Weight Test", NRL Memorandum Report 316 (June 1954). Puzak, P. P., and Babecki, A. J., "Normalization Procedures for NRL Drop-Weight Test", 38 (5), 209s (1959). Agnew, S. A., Mittelman, M. D., and Stout, R. D., "Some Observations on the Kinzel and Drop-Weight Tests", Welding Journal, 39 (5), 205s (1960).

Remarks - Very useful specimen for determining NDT (nil-ductility temperature) or the temperature at which a running cleavage crack will not be arrested. (See text.) Basically, it is a base-plate test but is used effectively as a screening test for subsequent explosion-bulge testing. Crack starter electrode recommended is 3/16-inch-diameter Murex Hardex N.

SPECIMEN 33

EXPLOSION-BULGE IMPACT SPECIMEN



Dimensions, inches						
L	W	t	t_1	h	ϕ	A
20	20	1 to 1-1/2	1/16	3/32	60°	5
30	30	1-1/2 to 2-1/2	1/16	3/32	60°	7

Dimensions shown are NRL standard; the over-all dimensions generally are adhered to; weld-joint dimensions varied; tested over wide range of temperature.

Materials Evaluated - Plain-carbon and low-alloy, high-strength steels.

Purpose of Test - Developmental, ductility, crack susceptibility, crack propagation, and weldability.

Number of Specimens Tested - NRL requires 5 to 6 samples; others use 3.

Nondestructive Inspection - Radiographic, with visual inspection used as an initial acceptance test.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, and data analysis.

Data Obtained - Impact energy, fracture appearance, reduction in plate thickness, and extent of cracking after testing.

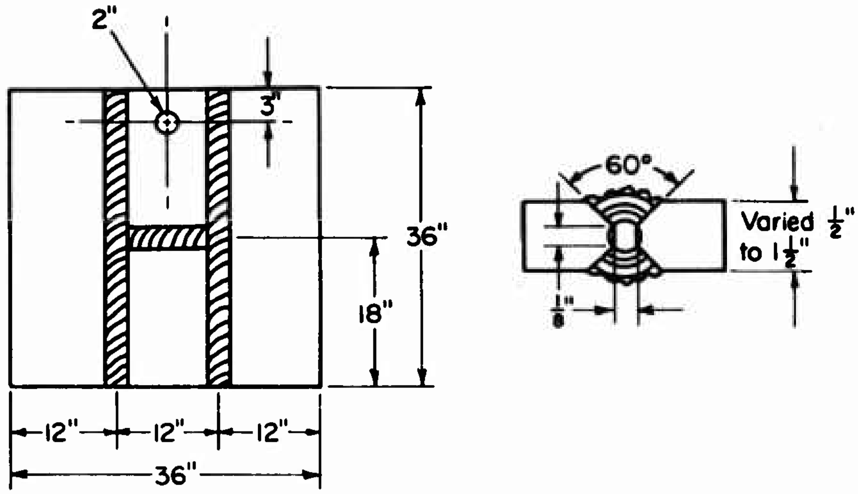
Specifications - NRL Standard Evaluation Procedures for Explosion-Bulge Testing, 15 March 1961.

References - Hartbower, C. E., "Mechanics of the Explosion Bulge Test", Welding Journal, 32 (7), 333s (1953). Puzak, P. P., Eschbacher, E. W., and Pellini, W. S., "Initiation and Propagation of Brittle Fracture in Structural Steels", ibid., 31 (12), 561s (1952).

Remarks - This is a good test specimen for composite weldment evaluation. Without the crack starter deposit, it evaluates weldment performance in the presence of any natural defects. With crack starter, it is a good evaluation of the fracture propagation characteristics of weld HAZ and unaffected base plate. This specimen used by U. S. Navy as acceptance test.

SPECIMEN 34

ARMY ORDNANCE BALLISTIC IMPACT SPECIMEN



Generally tested at 70 F in air. Some testing over a range of temperature for developmental purposes.

Materials Evaluated - Aluminum and magnesium alloys, titanium and titanium alloys, low-alloy, high-strength steels, rolled or cast armor steels.

Purpose of Test - Developmental, production quality, ductility, crack susceptibility, crack propagation, ballistic shock, and weldability.

Number of Specimens Tested - 1.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, and magnetic (where possible); visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Weld quality, weld inspection, measurements, data analysis, filler metal, joint geometry, welding procedure, and material.

Data Obtained - Impact energy, fracture appearance, and extent of cracking.

Specifications - MIL-A-46027 (ORD), MIL-W-12518 (ORD), MIL-W-12289 (ORD).

Remarks - Army Ordnance acceptance test based on arbitrary limits of acceptable ballistic-shock performance; not considered to have a direct relationship to actual performance of that joint in the hull of an armored vehicle; considerable effort has been made to find a cheaper and better evaluation test for Army Ordnance qualification of armor and armor weldments. Explosion-bulge (Specimen 33) and notched longitudinal-bend specimens appear reasonable substitutes for H-plate.

early work with impact testing was carried out near room temperature. Catastrophic brittle fractures of welded ships during World War II spurred research on notch toughness. Many types of notch-toughness tests were proposed and evaluated. Most were used for unwelded base-plate evaluation. As a result of this work, the importance of transition behavior – that is, the change of notch toughness with decreasing temperature that is observed in the body-centered cubic materials – was determined.

There are many factors that influence notch toughness. Among these factors are chemical composition, deoxidation practice, grain size, plate thickness, fabrication procedures, and structural design. The various notch-toughness tests provide only relative evaluations of materials and the effects on notch toughness of processing these materials. Then, how can the results obtained with one test be compared with those obtained with another test? Often, they cannot. For example, many attempts have been made to correlate the transition temperatures obtained from the various types of impact specimens. Unfortunately, there are a variety of criteria used to specify transition temperature. This is because the individual specimen performance often changes rather gradually and uniformly in the transition-temperature range. Therefore, an arbitrary level of performance must be selected as the transition or critical temperature. Two general bases for selecting the transition temperature are: (1) ductility criteria and (2) fracture criteria. The ductility transition temperature is defined as the highest temperature at which little or no plastic deformation precedes crack initiation. The fracture transition temperature is defined as the temperature below which crack propagation is predominantly by cleavage. Ductility criteria generally are associated with brittle crack initiation. Examples of transition temperatures based on ductility criteria are the temperatures at which the notch toughness is 10 ft-lb or the lateral contraction is 1 per cent. Fracture criteria generally are associated with crack propagation. An example of a transition temperature that is based on fracture criteria is the temperature at which the fracture is 50 per cent shear. Correlation of transition temperatures of various tests should be made on either ductility or fracture criteria – not on mixtures of the two. Much of the failure to obtain correlation between various tests is the result of indiscriminate mixing of the criteria used to judge performance. The ductility transition temperature is quite sensitive to mechanical factors and welding variables, while the fracture transition temperature is relatively insensitive. For the correlation of various tests, it has been shown that the choice of specimen is far less critical than the choice of cracking criteria used to establish the transition temperature.

For base-plate evaluations, the Charpy vee-notched specimen (Specimen 25) appears to be the best. Its usefulness stems partly from the fact that a tremendous amount of information has been collected on a wide variety of materials using this specimen. Also, the specimen is relatively simple, economical in use of material, easy to test over a wide range of temperature, and the data obtained are reproducible. The Charpy vee-notched specimen has been used extensively for determining weld-metal notch toughness. The location of the root of the notch with respect to weld microstructure will greatly influence the notch toughness. For example, location of the notch in the grain-refined region of a multipass weld will yield higher notch-toughness values than are obtained by locating the notch in the coarse, columnar structure of such a weld. The accuracy with which the notch can be located consistently has limited this specimen's usefulness for evaluating narrow heat-affected zones.

Notch shape is very important in notch-toughness specimens. Increasing notch sharpness raises the apparent transition temperature. For example, the Charpy vee-notched specimen will give higher values of transition temperatures for a given material than those obtained with the Charpy keyhole-notched specimen.

The drop-weight impact test (Specimen 32) was included only in the DMIC survey. Despite an indicated use by only 13 per cent of the polled organizations, it is used extensively for plain-carbon and low-alloy, high-strength steels. Basically, it is a base-plate test, but it has been used for weld-metal evaluation. The test is intended to measure the NDT (nil-ductility temperature) or the temperature at which a running cleavage crack will not be arrested. Since the drop-weight test does not evaluate the composite weldment (weld metal, heat-affected zone, and base plate), it is used more as a screening test. An impact test that is used to evaluate composite weldment performance is the explosion-bulge test (Specimen 33). The NDT in this test is that temperature at which the test specimen fails by cleavage without bulging. The NDT determined by the drop-weight test correlates well with the NDT determined by the explosion-bulge test. The Army Ordnance Ballistic H-Plate test (Specimen 34) is another composite weldment-evaluation test. Performance in this test is based on the length of cracks developed from ballistic impact. Although for years the H-plate has been a standard for evaluating fabrication techniques and the toughness performance of welded joints in Ordnance armor, attempts have been made to find a cheaper test. Research has shown that the explosion-bulge test can be substituted for the H-plate to determine toughness of Army Ordnance armor, provided extreme care is used in interpreting the test results.

Longitudinal bend specimens, such as the Kinzel test (Specimen 74), have been used to establish transition phenomenon. Although not an impact test, the Kinzel test is used for many of the same purposes. This test does not attempt to show direct correlation with service, but does give valuable information on the relative merits of steel compositions, heat treatment (before and after welding), and welding procedures. For example, this specimen is sensitive to heat-affected zone and weld-metal changes produced by variations in welding conditions. During testing, cleavage cracks initiate at the root of the notch in one of these zones and propagate into the base plate. The highest test temperature at which the propagating cleavage crack cannot be arrested in the base plate is the transition temperature. Two conditions must occur before brittle failure is evident in Kinzel tests. The test temperature must be low enough to permit both initiation of a cleavage crack and crack propagation through the remainder of the plate in a brittle manner.

None of the existing impact tests fully meets the requirement of direct correlation with service behavior. These tests can be used, however, to judge the relative performance of base materials and the effects of welding variables on the notch toughnesses of these base materials.

Fatigue

Fatigue tests were used principally by the aircraft companies. Only 9 out of the proposed 20 specimens were used. Of these 9, the axial fatigue specimen (Specimen 39) and the rotating-beam, bending specimen (Specimen 53) were used by over 10 per cent of

the organizations. However, the flat-plate, reverse-bending specimens, such as Specimens 50 and 51, should be used more than indicated by this survey. The constant-moment, bending-fatigue specimen (Specimen 51) can be used to evaluate a reasonably large weldment without removing the weld reinforcement. This type of specimen is often more representative of the fatigue conditions existing in service. Weld reinforcement often is removed from fatigue specimens since the weld reinforcement can influence fatigue behavior radically. Abrupt weld reinforcement or weld undercut can reduce fatigue strength to about one-half of its normal value. The drastic loss in fatigue strength because of poor weld contour becomes even more important in high-strength and ultrahigh-strength steel weldments. Savings afforded by the use of higher design and working stresses often are lost because of poor fatigue behavior.

Weldment fatigue strength can be influenced by welds having tensile strengths greatly different from those of the base material (mismatching). For this reason, the longitudinally welded plate bending specimens or axially loaded specimens should be preferred, since the composite weldment is strained equally.

Testing environment will greatly influence fatigue behavior. Fatigue cracks initiate on the surface (in the absence of serious internal flaws) very early during the fatigue life of the specimen (about 5 per cent of the fatigue life). This initiation appears to occur after about the same number of cycles of loading, regardless of the environment. However, the rate of propagation of the initiated fatigue cracks into the gross cracks that result in failure is strongly dependent on the testing environment.

Although standard fatigue specimens are used to some extent, much fatigue testing is done with nonstandard specimens. Deviation from the use of standard specimens usually is dictated by attempts to simulate actual weldments. Specimen standardization in these instances is unlikely. However, fatigue data used to study the effects of materials and welding variables should be obtained with standard specimens.

No attempt will be made here to discuss the various techniques of testing or methods of presenting fatigue data. This type of information is readily available in many fine textbooks and papers on the subject. Only an awareness of the importance of fatigue is hoped for here. The importance of fatigue testing is expected to increase greatly with expanding use of the notch sensitive, higher strength steels.

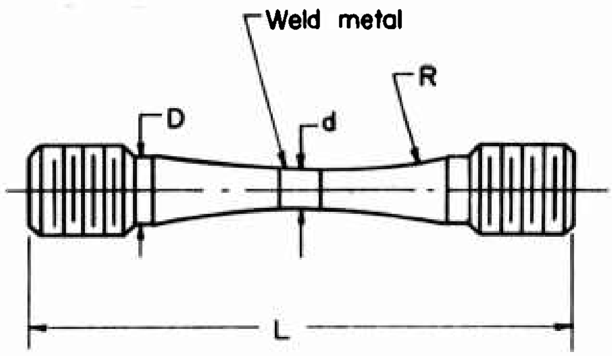
Stress Rupture and Creep

Stress-rupture and creep tests were used only to a limited extent by the organizations polled. A possible explanation is that organizations such as jet-engine manufacturers, who are most interested in high-temperature testing, were not included in either the DMIC or ARTC surveys.

Stress-rupture and creep testing differ only in that stress-rupture testing uses higher loads and strain rates and the tests are carried to failure. Both transverse- and longitudinal-weld stress-rupture and creep specimens were included in the survey. Only the transverse-stress-rupture specimen (Specimen 55) was used to any appreciable extent.

SPECIMEN 35

TRANSVERSE-WELD, AXIAL-FATIGUE SPECIMEN - ROUND



Dimensions, inches			
d	D	L	R
0.25	1.0	6	2.5
0.25	0.435	3-3/16	10

Test temperatures ranged from +70 to 1800 F; normally tested in air.

Materials Evaluated - All except refractory metals and their alloys and beryllium.

Purpose of Test - Developmental, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Average 12, varying from 3 to 25.

Nondestructive Inspection (in order of decreasing use) - Radiographic, magnetic (where possible), penetrant; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

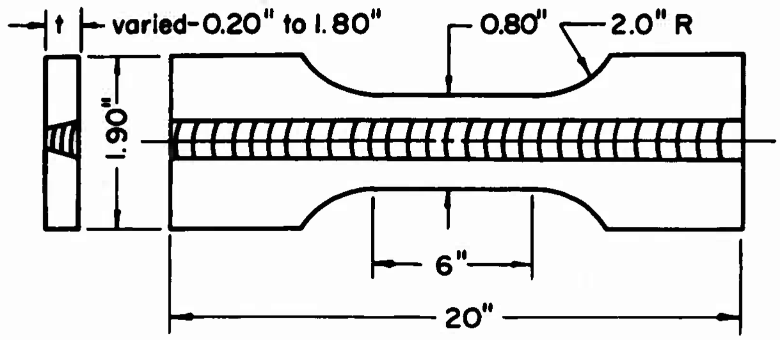
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Specimen designed to force failure in weld (in the absence of gross base-plate flaws); necessarily considered a weld evaluation and not a composite weldment (weld, HAZ, and base-plate test); should be used in conjunction with longitudinal-weld specimen.

SPECIMEN 36

LONGITUDINAL-WELD, AXIAL-FATIGUE SPECIMEN



Dimensions varied with organization: usually tested in air at room temperature; tested with and without weld reinforcement, depending on service conditions.

Materials Evaluated - Aluminum and magnesium alloys, titanium and titanium alloys, plain-carbon, low-alloy high-strength, ultrahigh-strength, and high-alloy steels.

Purpose of Test - Developmental, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Usually 5, varying from 3 to 6; however at least 10 should be used to establish S-N curve.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, and magnetic (where possible); visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

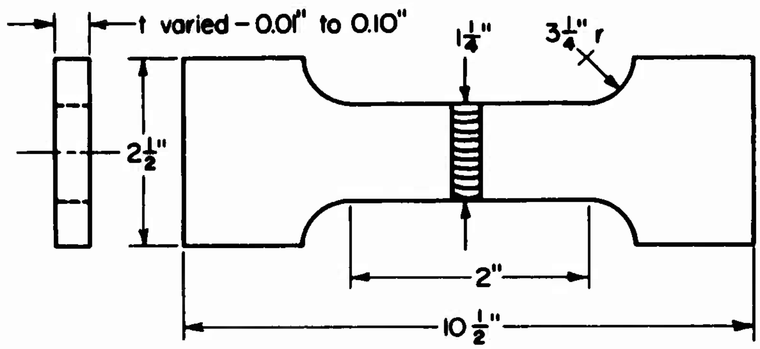
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only

Remarks - Specimen evaluates composite weldment; the effects of weld-metal "mis-matching" are the same for this specimen as for static tension specimen (see section on tension tests).

SPECIMEN 39

TRANSVERSE-WELD, AXIAL-FATIGUE SPECIMEN – FLAT



Dimensions varied greatly; tested over wide range of temperature from -100 to +1600 F, usually in air; tested with and without weld reinforcement depending on service conditions.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Average 10, varying from 3 to 25.

Nondestructive Inspection (in order of decreasing use) - Radiographic, penetrant, and magnetic (where possible); visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

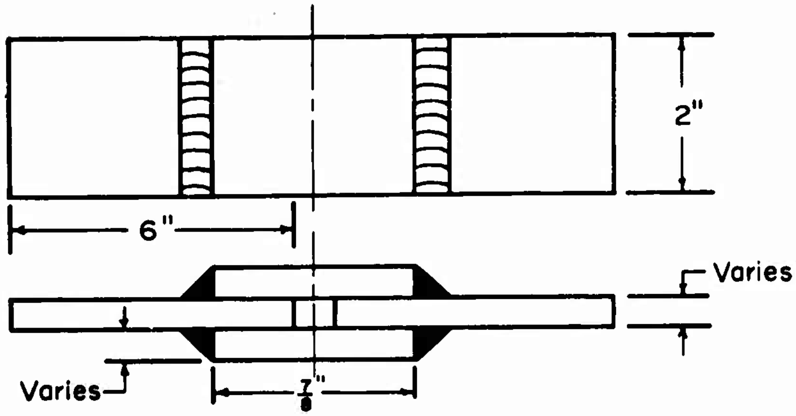
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Specimen, when tested with weld reinforcement, is sensitive to bend shape, weld undercut, weld-metal strength (overmatching or undermatching).

SPECIMEN 47

AXIAL FILLET-WELD FATIGUE SPECIMEN



Thickness dimensions not reported but probably can be used on plates up to 1/2 inch thick without difficulty.

Materials Evaluated - All except beryllium and refractories.

Purpose of Test - Developmental, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - 3 reported but at least 10 should be used to establish S-N curve.

Nondestructive Inspection - Penetrant with visual inspection as an initial acceptance test.

Important Variables - Specimen geometry (for symmetry), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

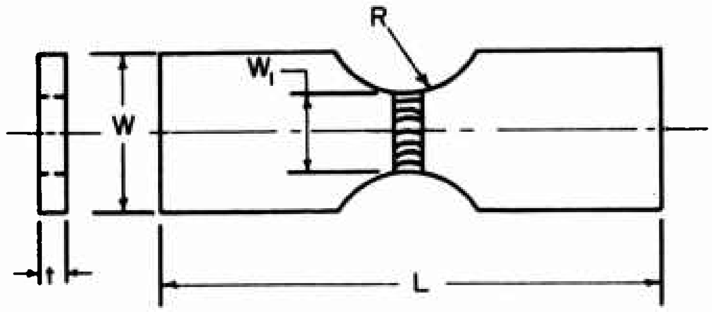
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Very limited use but considered good test specimen; it is recommended that the specimen edges be machined to eliminate the effects of weld craters at ends.

SPECIMEN 50

TRANSVERSE-WELD, BENDING-FATIGUE SPECIMEN



Dimensions, inches				
L	W	W_1	R	t
4	1-1/4	3/4	1/2	1/8
9-1/4	2	1-1/2	3	1/8

Dimensions varied greatly; usually tested at room temperature in air; tested with and without weld reinforcement depending on service conditions.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens Tested - Usually 10.

Nondestructive Inspection (in order of decreasing use) - Radiographic, magnetic (where possible), and penetrant; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry (with or without weld reinforcement), weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

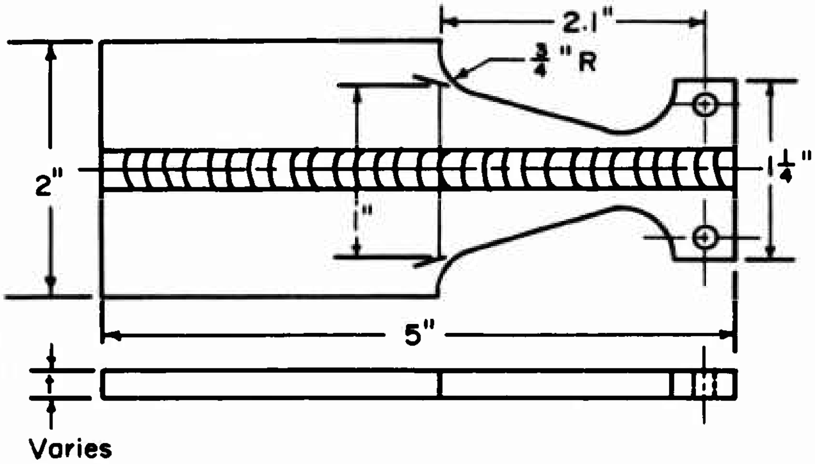
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Specimen designed to force failure in weld or HAZ; consequently, not a composite-weldment test specimen.

SPECIMEN 51

CONSTANT-MOMENT, BENDING-FATIGUE SPECIMEN



Dimensions varied greatly; usually tested at room temperature in air; tested with and without weld reinforcement depending on service conditions.

Materials Evaluated - All materials.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens - 10.

Nondestructive Inspection (in order of decreasing use) - Radiographic, magnetic (where possible), and penetrant; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

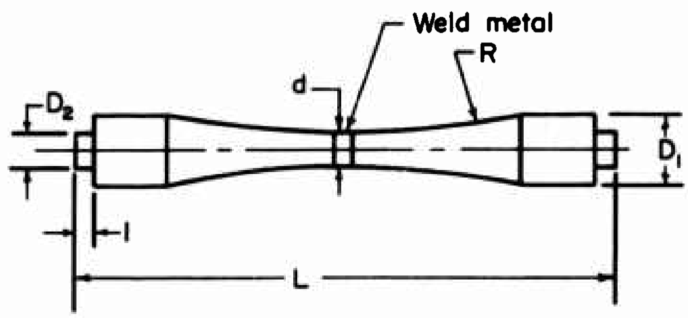
Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - Company specifications only.

Remarks - Considered good weldment evaluation; because of constant-stress over a considerable portion of specimen, failure will occur at weakest point such as a weld defect.

SPECIMEN 53

ROTATING-BEAM, BENDING-FATIGUE SPECIMEN



Dimensions, inches					
l	L	d	D_1	D_2	R
0.50	10.21	1.00	1.50	0.640	9.00
--	3-7/16	0.300 ±0.003	0.480	--	9-7/8

Second set of dimensions are for standard R. R. Moore specimen with drilled and tapped specimen ends; specimens usually tested at room temperature in air.

Materials Evaluated - All.

Purpose of Test - Developmental, production quality, fatigue strength, weldability, and design allowables.

Number of Specimens - Usually 10, varying from 3 to 12.

Nondestructive Inspection (in order of decreasing use) - Radiographic, magnetic (where possible), and penetrant; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen preparation, specimen positioning, measurements, and data analysis.

Data Obtained - Fatigue strength, cycles to failure, and endurance limit.

Specifications - QQ-M-151 (R. R. Moore).

Remarks - Because of generous radius, failure is likely to occur in weld, HAZ, or base plate.

Most stress-rupture and creep testing has been on unwelded base plate. However, the results of tests of welded and unwelded specimens would be expected to be the same so long as the composition of the filler metal matched that of the base plate and the grain sizes of welded and unwelded specimens were comparable. Welding may have a considerable effect on the stress-rupture and creep properties of the weldment if the welds differ greatly in strength from that of the base metal. It is desirable to use both transverse and longitudinal weld-metal specimens as discussed in the section on tension tests.

Specimen design, testing equipment, and testing procedures generally are identical for creep and stress-rupture testing. One significant difference in the two tests is the technique used to measure elongation. In the creep test, the total strain is usually less than 0.5 per cent. In the rupture test, the total strain may amount to 50 per cent or more. Also, the methods of reporting data are different for the two tests. Two standards for creep strength usually are used in this country: (1) the stress producing a creep rate of 0.0001 per cent per hour often expressed as 1 per cent for 10,000 hours (about 1 year); and (2) the stress producing a creep rate of 0.00001 per hour or 1 per cent per 100,000 hours (about 11 years). The second standard is used in designing rapidly moving parts, such as in steam turbines, in which the total creep must be very small. Stress-rupture values are usually reported as the stress to produce failure in 100, 1000, 10,000, and 100,000 hours.

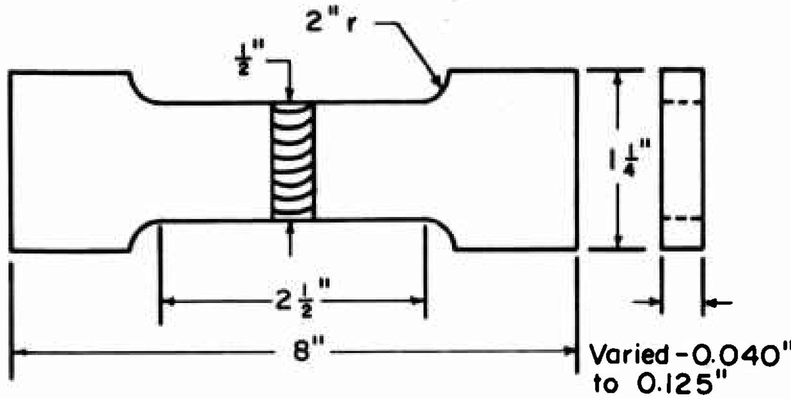
Crack Susceptibility

Crack-susceptibility tests of one type or another were used by almost 50 per cent of the organizations surveyed. A very large number of crack-susceptibility tests have been devised and used during the development of welding. Only 12 of these tests were included in the survey. Of these, only the cruciform test (Specimen 68) and the circular-patch test (Specimen 61) were used to any appreciable extent. The cruciform test is an underbead or heat-affected-zone cracking test of extreme severity. The degree of restraint increases as each fillet weld is deposited. The major criticism of this test is that hydrogen can migrate from one heat-affected zone to the other. Thus, the hydrogen content of the last joint deposited, when the restraint is highest, may be increased. Such an increase can lead to an increase in cracking. The circular-patch test is basically a weld-metal cracking test. It is more likely to produce hot cracking rather than the cold or underbead cracking observed in the cruciform test.

In discussing crack-susceptibility tests, it is desirable to distinguish between hot cracking and cold cracking. Weld hot cracking (sometimes called super-solidus cracking) is believed to occur during freezing of the molten weld metal. Hot cracking probably is caused by eutectic-type liquid films that persist at the grain boundaries over a relatively wide temperature range. The strains produced from shrinkage as well as external restraint tend to pull the solidified grains apart at the liquid interface, thus producing cracks. Accordingly, all hot cracks are intergranular. Heat-affected-zone hot cracking is believed to be caused by liquation of the grain boundaries at temperatures just below the nominal alloy solidus. Although the mechanism of heat-affected-zone hot cracking is not known, segregated low-melting compounds, such as FeNiS and other inclusions, may liquate in the high-temperature portions of the heat-affected zone and form cracks. Fissuring in stainless steel is believed by many to have this origin. Heat-affected-zone hot cracking is unlikely if the weld-metal solidus is lower than the base-plate solidus.

SPECIMENS 55 AND 57

TRANSVERSE-WELD, STRESS-RUPTURE, AND CREEP SPECIMENS



Dimensions and test temperature varied greatly; tested with and without weld reinforcement depending on service conditions.

Materials Evaluated - All.

Purpose of Test - Developmental, strength, ductility, weldability, and design allowables.

Number of Specimens Tested - Usually 3, varying from 2 to 10.

Nondestructive Inspection (in order of decreasing use) - Radiographic, magnetic (where possible), and penetrant; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, test-temperature control, measurements, and data analysis.

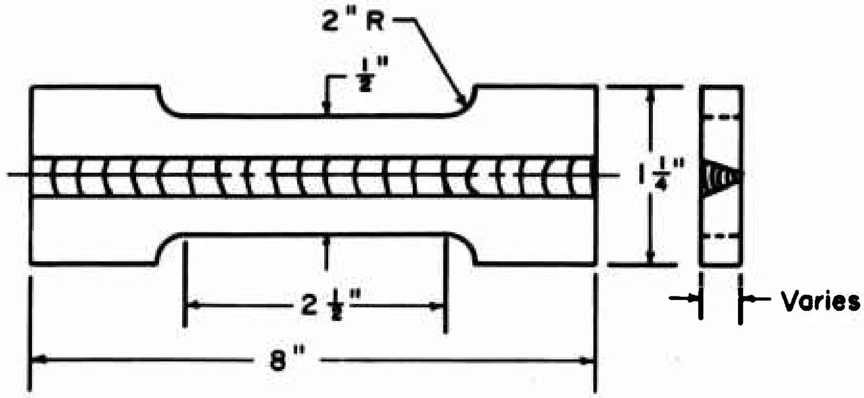
Data Obtained - Time to failure, stress to rupture in 100, or 1000 hours, elongation in 1/2 inch and in 2 inches, and reduction of area.

Specifications - Company specifications.

Remarks - The same general remarks concerning the effects of weld-metal strength that were made of tension specimens apply (see section on tension tests).

SPECIMENS 56 AND 58

LONGITUDINAL-WELD, STRESS-RUPTURE, AND CREEP SPECIMENS



Dimensions shown are same as for transverse-weld specimen (Specimen 55); tested with and without weld reinforcement depending on service conditions.

Materials Evaluated - Low-alloy high strength, ultrahigh strength, and high-alloy steels.

Purpose of Test - Developmental, strength, and weldability.

Number of Specimens Tested - 3.

Nondestructive Inspection (in order of decreasing use) - Radiographic, magnetic (where possible), and penetrant; visual inspection is used as an initial acceptance test in conjunction with the other tests.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, test-temperature control, measurements, and data analysis.

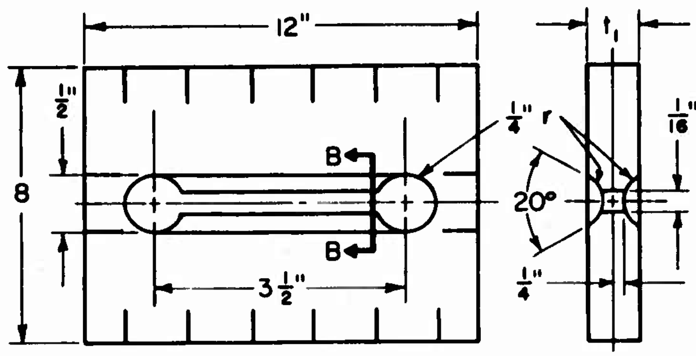
Data Obtained - Time to failure, stress to rupture in 100 or 1000 hours, elongation in 2 inches, and reduction in area.

Specifications - Company specifications.

Remarks - Only one organization used this specimen; the dimensions shown are reasonably close to those used by the single organization, but were made to conform to those of Specimen 55.

SPECIMEN 59

CRACK-SUSCEPTIBILITY SPECIMEN – LEHIGH



Section B—B

Dimensions, inches									
l_1	L	W	X	W_2	W_3	t_1	t_2	$\phi^{(a)}$	R
3-1/2	12	8	Var.	1/2	1/16	<1	1/4	20°	1/4
5-1/2	12	8	Var.	1/2	1/16	>1	1/4	20°	1/4

Dimension X usually varied in 1/2-inch increments. Temperature of base plate at time of depositing test weld varied depending on condition studied, i.e., preheat, ambient temperature, etc.

Materials Evaluated - All (used only for steels in survey).

Purpose of Test - Crack susceptibility; developmental.

Number of Specimens Tested - Usually 2 (see test procedure below)

Nondestructive Inspection (in order of decreasing use) - Visual, penetrant, magnetic, and radiographic.

Important Variables - Specimen geometry, weld quality, weld inspection, and data analysis.

Data Obtained - Degree of restraint necessary to cause cracking.

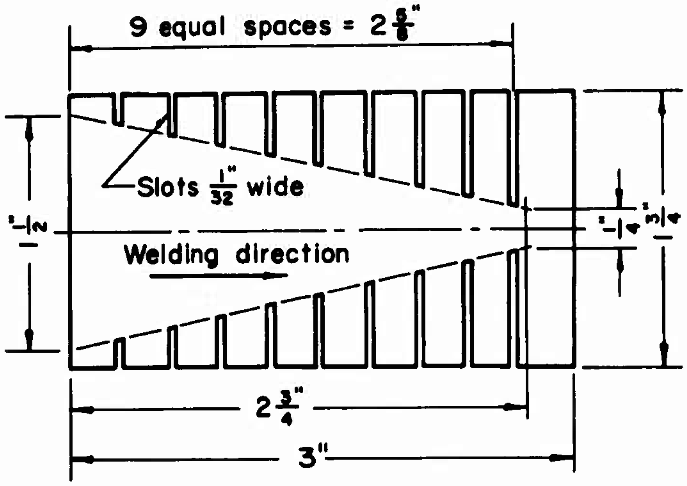
Specifications - None.

References - Stout, R. D., and Doty, W. D., Weldability of Steels, Welding Research Council, 1953, pp 232-234. Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Remarks - This test was designed to obtain, quantitatively, the degree of restraint necessary to cause weld-metal cracking during cooling. It is a go - no go test and requires several specimens to estimate cracking susceptibility. Variables that can be studied include base plate, filler metal, preheat, postheat, heat input, and effects of multipass welding. Generally, the first specimen welded will be under full restraint (no saw cuts). If this specimen cracks, another specimen is welded that contains less restraint (saw cuts). Sufficient specimens are welded until a restraint level is reached at which no further cracking occurs.

SPECIMEN 60

CRACK-SUSCEPTIBILITY SPECIMEN – HOULDCROFT



Dimensions shown recommended for 1/16-inch thick sheet; dimensions increased 50 per cent for 1/8-inch-thick sheet. Arc initiated at edge of plate to initiate a weld crack and then welded in direction shown; crack will propagate (if hot-crack sensitive) until the degree of restraint is insufficient to continue crack; the length of crack is a measure of hot-cracking sensitivity; complete weld penetration must be obtained and a constant weld width maintained; specimens should not be rigidly clamped down during welding; usually welded at room temperature in air.

Materials Evaluated - All.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 6 (mean crack length computed).

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, and dye penetrant.

Important Variables - Specimen geometry, weld quality, complete weld penetration, crack-length determination, and data analysis.

Data Obtained - Crack-susceptibility index in terms of crack length.

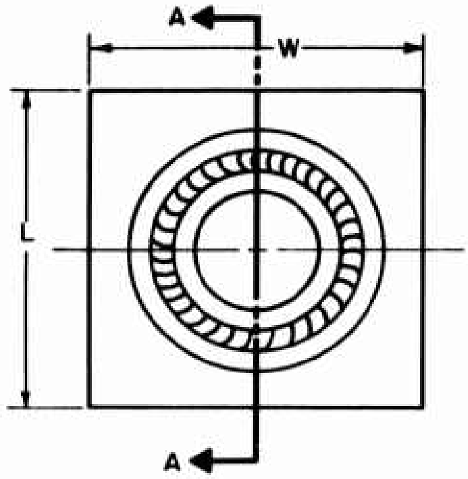
Specifications - None.

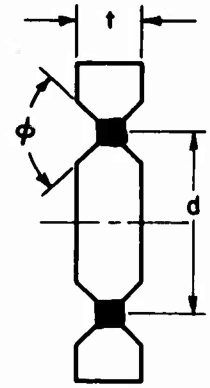
References - Houldcroft, P. T., "A Simple Cracking Test for Use With Argon Arc Welding", British Welding Journal, 2 (10), 471 (1955). Wilkinson, F. J., Cottrell, C. L. M., and Huxley, H. V., "Calculating Hot Cracking Resistance of High Tensile Alloy Steels", ibid., 5 (12), 557 (1958). Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Remarks - Useful for evaluating relative cracking sensitivity of various materials; this is a hot-cracking test for inert-gas, tungsten-arc welds in thin sheet; it is believed that the test could be extended to consumable-electrode welding providing wire diameter is sufficiently small; specimen is sensitive to welding speed.

SPECIMEN 61

CRACK-SUSCEPTIBILITY SPECIMEN - CIRCULAR PATCH





Section A-A

Dimensions, inches				
L	W	ϕ	d	t
12	12	90°	Var.	Var.
5	5	0°	2	0.076

Dimensions varied greatly but dimensions shown are recommended for plates (1/4 inch and thicker) and sheets; the variable dimensions are discussed in Remarks below. Tested in air at room or preheat temperature.

Materials Evaluated - All.

Purpose of Test - Developmental, crack susceptibility, study effects of welding procedures and restraint.

Number of Specimens Tested - Usually 1 per patch diameter, d, to establish restraint level necessary to cause cracks.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, penetrant, and magnetic (where possible).

Important Variables - Specimen geometry, weld quality, weld inspection, welding procedures, and data analysis.

Data Obtained - Extent and type of cracking.

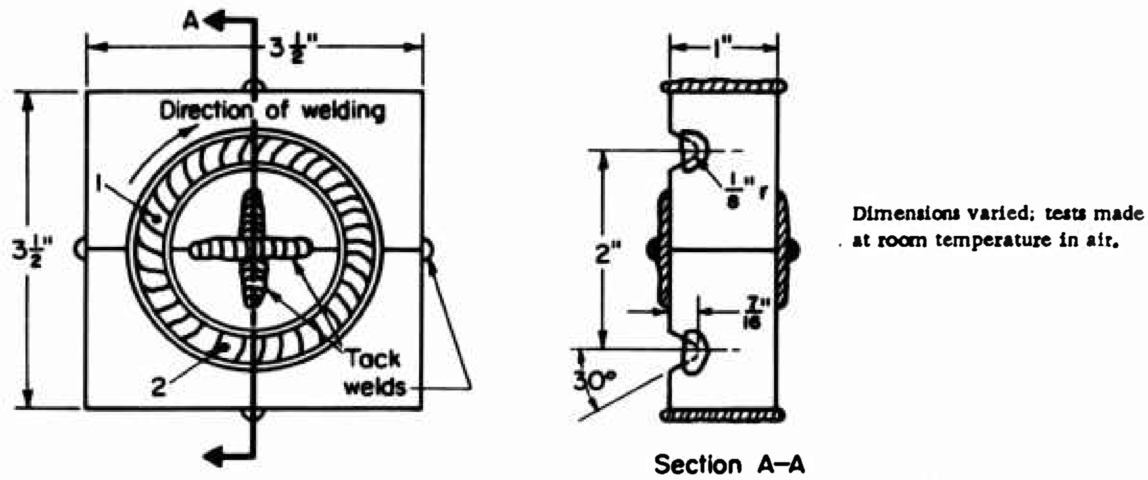
Specifications - Company specifications only.

References - Hackett, J. E., and Seaborn, L. O., "Evaluation of the Circular-Patch Weld Test", Welding Journal, 31 (8), 387s (1952). Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Remarks - This test evaluates both hot- and cold-cracking tendencies of welds and HAZ's; although this basically is a go - no go type of test, a quantitative evaluation of cracking susceptibility can be obtained by varying the patch diameter, d; decreasing "d" increases restraint; it has been shown that residual stresses of the order of the base-plate yield strength can be obtained by maintaining the patch-diameter/plate-width ratio, d/L, between 0.2 and 0.3. Based on this criterion, it was concluded that a 12-inch-square plate was optimum size.

SPECIMEN 62

CRACK-SUSCEPTIBILITY SPECIMEN – MODIFIED CIRCULAR RESTRAINT



Materials Evaluated - Low-alloy high-strength, ultrahigh-strength, and high-alloy steels.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - 1.

Nondestructive Inspection (in order of decreasing use) - Visual, magnetic (where possible), and penetrant.

Important Variables - Specimen geometry, weld quality, weld inspection, welding procedures, and data analysis.

Data Obtained - Extent and type of cracking; cracking usually expressed as per cent of total length of weld.

Specifications - Company specifications only.

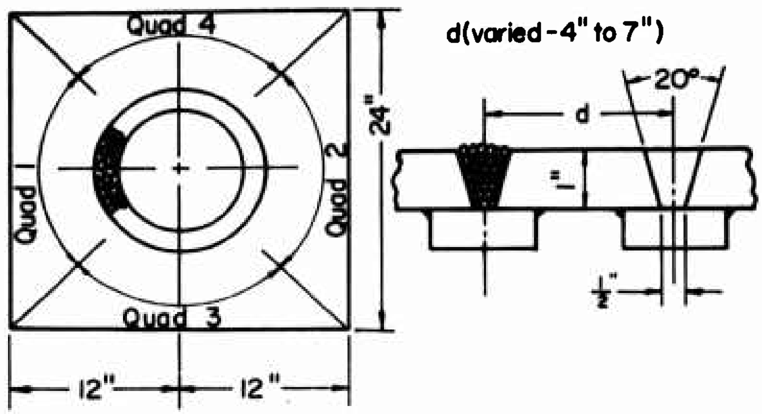
References - Hoerl, A., and Moore, T. J., "The Welding of Type 347 Steels", Welding Journal, 36 (10), 442s (1957). Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Test Procedure - The four blocks are surface ground on their mating edges, clamped together, and tack welded; groove in assembly is machined; weld is initiated at Point 1 (in figure) and proceeds in clockwise direction to Point 2; after specimen has cooled to below 200 F, the remaining 120 degrees is welded with another test electrode; specimen examined for weld cracks.

Remarks - Test for hot and cold cracking of welds and HAZ's; essentially a go-no go test but could be made quantitative by varying diameter of groove; expensive test.

SPECIMEN 64

CRACK-SUSCEPTIBILITY SPECIMEN – U. S. NAVY CIRCULAR PATCH



Dimensions shown are MIL-E-986C; "d" varies with coated electrode diameter, increasing from 4 to 7 inches as electrode diameter increases from 5/32 to 5/16 inch; for Grade HT steel, preheat and interpass temperature is 0 F; for Grade STS, it is 75 F (+25 F tolerance).

Materials Evaluated - Low-alloy high-strength steels.

Purpose of Test - Developmental, crack susceptibility, and weldability.

Number of Specimens Tested - Surveyed organizations used 2 specimens but specifications require 1 per each size of electrode.

Nondestructive Inspection - Visual, radiographic, and penetrant.

Important Variables - Specimen geometry, weld quality, weld inspection, and test-temperature control.

Data Obtained - Extent of cracking; if welded specimen is radiographically sound, microsections cut from each quadrant for examination for cracks, and weld-metal hardness.

Specifications - MIL-E-22200 and MIL-E-986 C.

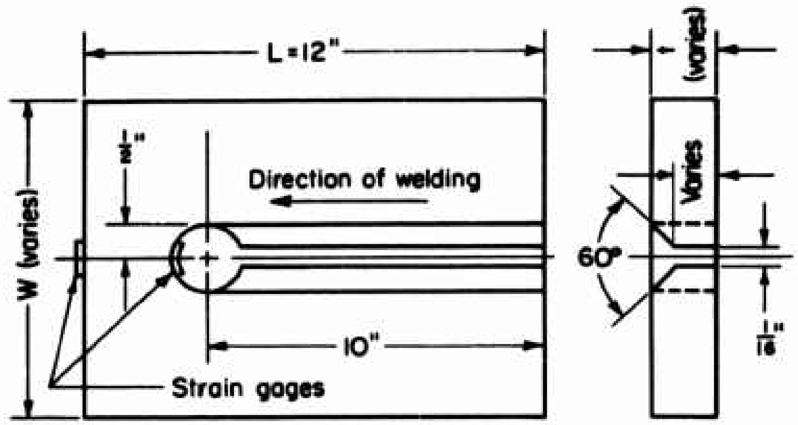
References - Wooding, W. H., "Welding Air-Hardening Alloy Steels", Welding Journal, 29 (11), 552s (1950). Stout, R. D., and Doty, W. D., Weldability of Steels, Welding Research Council, 1953, p 236. Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Test Procedure - Each quadrant completely welded in numerical sequence shown in sketch; the number of layers using a "2-1/2-diameter split-weave" buildup sequence depends on electrode diameter; completed weld allowed to stand 24 hours; if no cracks visible, a concentric disk 2 inches larger in diameter than weld is flame cut from plate, surface machined on each side, and radiographed; if weld is sound, then sections for metallographic examination and hardness tests are cut from each quadrant.

Remarks - An acceptability test for electrode qualification; considered a severe test for hot and cold cracking.

SPECIMEN 65

CRACK-SUSCEPTIBILITY SPECIMEN – U. S. NAVAL RESEARCH LABORATORY



Restraint varied by varying L, W, and t; normally L held constant; example - for t = 1/2 inch, W varied from 6 to 10 inches.

Materials Evaluated - Although only used for low-alloy, high-strength steels by surveyed organizations, probably could be used for all materials.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 3.

Nondestructive Inspection - Visual and radiographic.

Important Variables - Specimen geometry, weld quality, welding conditions, weld inspection, instrumentation, measurements, and data analysis.

Data Obtained - Extent and type of cracking.

Specifications - None.

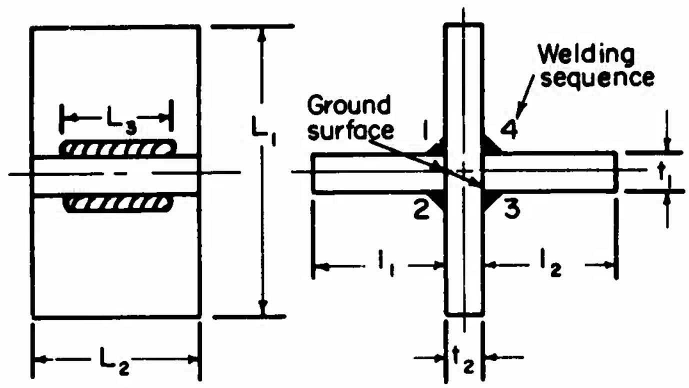
References - White, S. S., Moffatt, W. G., and Adams, C. M., Jr., "Dynamic Measurements of Stress Associated With Weld Cracking", Welding Journal, 37 (4), p 185s (1958). Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Test Procedure - Weld deposited in groove beginning at edge of plate and proceeding toward hole; strains from two gages recorded continuously during welding and as weld cools to room temperature; gross cracking indicated from strain measurements.

Remarks - A semiquantitative test to determine if and when cracking occurs; cracking usually occurs along weld and occasionally in HAZ; simultaneous monitoring of strain, time, and temperature of weld can provide useful information regarding crack formation, particularly delayed cracking (hydrogen induced).

SPECIMEN 68

CRACK-SUSCEPTIBILITY SPECIMEN - CRUCIFORM



Dimensions, inches						
l_1	l_2	L_1	L_2	t_1	t_2	L_3
6	6	12	12	Var.	Var.	6
4	4	8	12	1/4-2	1/4-2	6
3-t	3-t	3	3	0.04	0.04	3

Dimensions varied greatly; the first set of dimensions are preferred; the other sets of dimensions are given to show the range of dimension variation reported; tests usually made at room temperature in air.

Materials Evaluated - All (but used mostly for steels).

Purpose of Test - Developmental, crack susceptibility, and weldability.

Number of Specimens Tested - Usually 1, varying from 1 to 5.

Nondestructive Inspection (in order of decreasing use) - Visual, penetrant, radiographic, magnetic (where possible), and ultrasonic.

Important Variables - Specimen geometry, weld quality, weld inspection, specimen positioning, measurements, and data analysis.

Data Obtained - Extent of cracking.

Specifications - "Procedure: Armor Plate Crack Sensitivity Test", Research Group Ordnance Advisory Committee on Welding of Armor.

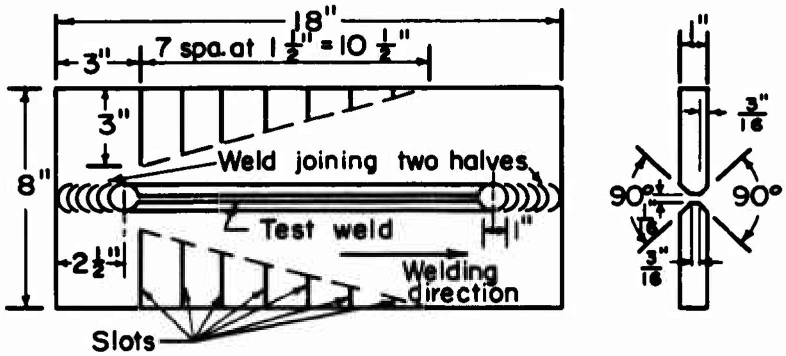
References - Weiss, S., Ramsey, J. N., and Udin, H., "Evaluation of Weld-Cracking Tests on Armor Steel", Welding Journal, 35 (7), 348s (1956). Poteat, L. E., and Warner, W. L., "The Cruciform Test of Plate-Cracking Susceptibility", ibid., 39 (2), 70s (1960). Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Test Procedure - Fillet welds are deposited in sequence shown; temperature at start of each fillet maintained constant (either room temperature or predetermined preheat temperature); after welding, specimen is aged at room temperature for 48 hours, then stress relieved at 1150 F for 2 hours (heating and cooling from 1150 F at the rate of 100 F per hour); specimen is inspected for cracking and cross sections are cut for metallographic examination.

Remarks - Considerable uncertainty regarding usefulness of specimen; Poteat and Warner (see references) concluded that the test was more sensitive to testing conditions (temperature, fit-up, plate size, etc.) than it is to differences in crack susceptibility of the base metal used; they concluded that the cruciform test in its present form, under test conditions in a production shop, was unsuitable as a crack-susceptibility test for armor steel; its usefulness for other materials appears equally uncertain.

SPECIMEN 82 - EXTRA

CRACK-SUSCEPTIBILITY SPECIMEN - BATTELLE



Test weld deposited in groove in direction shown; welded with or without preheat in air.

Materials Evaluated - Plain-carbon, low-alloy high-strength, and ultrahigh strength steels.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 3.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, and penetrant.

Important Variables - Specimen geometry, weld inspection, crack-length determination, and data analysis.

Data Obtained - Unslotted width of specimen at point where hot cracks initiate; this is considered the cracking index of the test weld.

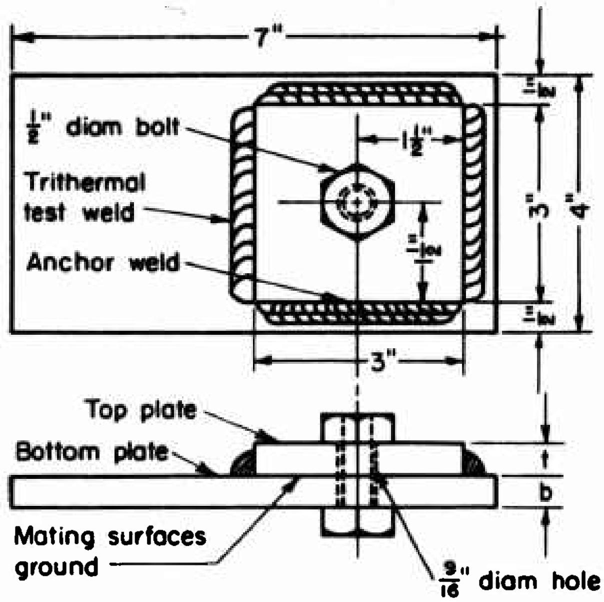
Specifications - None.

References - Mishler, H. W., Monroe, R. E., and Rieppel, P. J., "Determination of the Causes of Weld Metal Cracking in High Strength Steels and the Development of Heat-Treatable Low-Alloy Steel Filler Wires for Use With the Inert-Gas-Shielded Arc Welding Process", WADC Technical Report 59-531 (August 1959).

Remarks - Considered a good, semiquantitative test for evaluating relative cracking susceptibility; had advantage of limited testing to determine a cracking index as compared with other go - no go tests.

SPECIMEN 81 - EXTRA

CRACK-SUSCEPTIBILITY SPECIMEN - CONTROLLED THERMAL SEVERITY (CTS)



Dimensions t and b varied to change thermal severity; the thermal severity number is obtained from the following formula:

TSN = 4(t+b) for bithermal welds

TSN = 4(t+2b) for trithermal welds.

After specimen assembled and anchor welds deposited, assembly allowed to cool to room temperature for depositing bithermal test weld; similarly, specimen cooled to room temperature before trithermal weld deposited; severity of cracking determined by measurements of crack length on metallographic sections.

Materials Evaluated - Plain-carbon and low-alloy, high-strength steels.

Purpose of Test - Developmental, weldability, and crack susceptibility.

Number of Specimens Tested - Usually 3.

Nondestructive Inspection - Visual, penetrant, and magnetic.

Important Variables - Specimen geometry, weld quality, crack detection, and data analysis.

Data Obtained - Extent of cracking.

Specifications - None.

References - Cottrell, C. L. M., "Controlled Thermal Severity Cracking Test Simulates Practical Welded Joints", Welding Journal, 33 (6), 257s (1953). Borland, J. C., "Cracking Tests for Assessing Weldability", British Welding Journal, 7 (10), 623 (1960).

Remarks - Test based on assumption that extent of hard-zone cracking is mainly dependent on cooling rate at about 572 F (300 C), as measured in HAZ adjacent to fusion line; when a critical rate of cooling for a given electrode-steel combination is exceeded, cracking is supposed to occur irrespective of external restraint applied; test evaluates effects of weld and HAZ cooling rates and not external restraint.

Since hot cracking is considered to be caused by intergranular, eutectic-type liquid films, chemical composition of the filler metal and base plate is of prime importance. Extensive research done at Battelle and elsewhere has shown that tramp elements such as sulfur and phosphorus promote hot cracking. Restraint promotes hot cracking, but a quantitative evaluation of the effect of variations in restraint is lacking. Preheat and postheat have little effect on hot cracking. The prevention of hot cracking must come from control of chemical composition.

Cold cracking is caused by the interaction of three factors; (1) hydrogen, (2) a hardened microstructure, and (3) stress. As the name implies, cold cracking occurs at or near room temperature and is transgranular in nature. Actually, cold cracking can occur at any temperature below the austenite-martensite transformation (M_s) temperature. The role of hydrogen in producing underbead or cold cracking is well established. The exact conditions of hydrogen concentration, microstructure, and state of stress necessary for the formation of cold cracks are not known. However, the combination of any two of the three conditions, if sufficiently severe, can produce cold cracks. Cracking tests merely assess the over-all conditions necessary to form cracks.

The factors affecting cold cracking are chemical composition of the base plate and filler wire, hydrogen content of the arc atmosphere, degree of restraint, and welding conditions. Chemical composition and the welding conditions determine the type of microstructure formed in the weld and heat-affected zone. A hardened microstructure is one of the three factors involved in cold cracking. Preheat and postheat reduce the cooling rate and so favor the formation of softer, more ductile microstructures. Preheat and postheat also reduce shrinkage stresses (effectively reducing restraint). Equally important, preheating and postheating aid the escape of hydrogen from the weld and heat-affected zone. In general, cold cracking can be eliminated by proper choice of welding procedures.

It is necessary to understand the factors influencing cracking to select the proper cracking susceptibility test. The fact that many factors are involved accounts, in part, for the many varieties of tests. Specimens 59 to 65 (Table 1) are weld-metal cracking tests (principally hot cracking, but necessarily including cold cracking). Specimens 68, 69, and 79 to 82 are cold-cracking tests. The common variable in most of these tests is restraint. The degree of restraint is changed in a number of ways. Changes in plate thickness afford changes in restraint in the cruciform test. Changes in patch diameter produce varying restraint in the many circular-patch tests. Restraint in the Lehigh specimen is varied by changing the depth of the saw cuts on the specimen sides. It is necessary with each type of specimen to run a series of tests to establish the degree of restraint necessary to cause cracking. Each individual specimen effectively is a go – no go test. A variable-restraint specimen such as the Houldcroft test can provide a relative cracking index with a minimum of specimens. Regardless, the cracking test should be selected to highlight the particular variable being studied.

Crack Propagation

Crack propagation tests were used by only a few of the polled organizations. Only organizations interested in applications involving high-strength materials probably would

be interested in this type of testing. Crack propagation tests are used to evaluate the ability of a material to resist the propagation of an existing crack or flaw under the application of load. Interest in fracture-propagation characteristics of high-strength materials was most recently stimulated by the many catastrophic failures of rocket-motor cases during hydrotesting. No attempt will be made here to discuss the engineering-mechanics aspects of brittle fracture (or fast fracture as it is more generally called in high-strength materials). Such a discussion is covered in DMIC Report 124, "Current Tests for Evaluating Fracture Toughness of Sheet Metals at High Strength Levels", and in DMIC Report 147, "The Factors Influencing the Fracture Characteristics of High-Strength Steel".

Considerable work has been done to develop test specimens and testing techniques for studying the fracture propagation characteristics of high-strength steels. The specimens and procedures have been developed principally for base-plate evaluation, but have been used for weldments. The three most widely used specimens are included (Specimens 71, 72, and extra Specimen 83. Each specimen has advantages and disadvantages. The Allison bend specimen is the simplest to produce and test. The specimen does not use a preplaced crack so that its use in evaluating the fracture-propagation characteristics of weld metals is uncertain. The other two specimens use a preplaced notch or crack so that the fracture-propagation characteristics of weld metals can be studied.

The ASTM Committee on Fracture Testing of High-Strength Sheet Materials is trying to standardize fracture-propagation testing as to specimen type and size, as well as testing procedures. The Minutes of the meetings of this Committee provide a valuable discussion of fracture dynamics of high-strength materials.

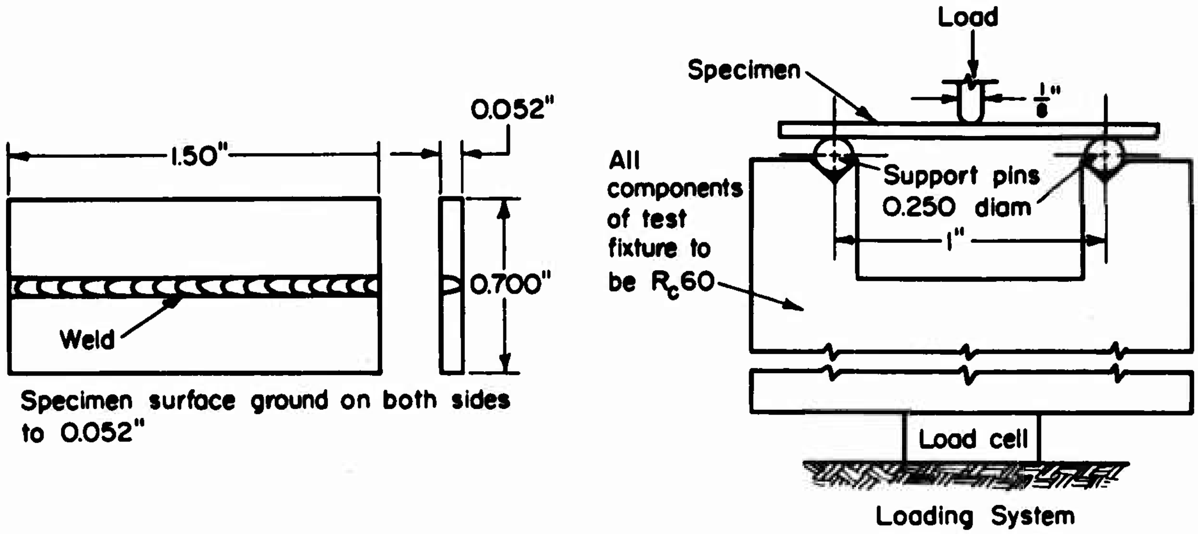
Weld Soundness

Weld soundness tests of some type were used by 50 per cent of the organizations included in the DMIC survey. The Bead-on-Plate-Weldability Test (Specimen 79) is one of the simplest and yet most underrated tests for weldments. Information concerning underbead-cracking tendencies, porosity, inclusions, and microstructure can be easily determined with this test. It readily lends itself to the study of the effects of welding variables such as heat input, preheat, postheat, and stress-relief treatment on microstructure. Hardness traverses of the cross-sectioned specimen give reasonable estimates of strength of the weld, heat-affected zone, and unwelded base plate of many materials.

The nick-break and fillet-weld soundness tests only provide an estimate of weld soundness. The dimensions of these specimens are not critical and can be easily varied to fit the application. However, standards have been established for nick-break and fillet-weld soundness tests.

SPECIMEN 83 - EXTRA

CRACK-PROPAGATION SPECIMEN - ALLISON INSTRUMENTED BEND TEST



Dimensions shown are recommended by ASTM for base-plate evaluation (see Reference). Other dimensions may be used but a minimum width-to-thickness ratio of 10 is recommended.

Materials Evaluated - All of very high strength.

Purpose of Test - Developmental, crack susceptibility, crack propagation, and weldability.

Number of Specimens Tested - Usually 3.

Nondestructive Inspection - All types.

Important Variables - Specimen geometry, weld quality, weld inspection, testing equipment, specimen positioning, strain-rate control, instrumentation, test-temperature control, measurements, and data analysis.

Data Obtained - Load-time curves from which fracture toughness and instrumented-bend test parameter can be calculated.

Specifications - None.

Reference - "Fracture Testing of High Strength Sheet Materials", ASTM Committee on Fracture Testing of High Strength Sheet Materials, ASTM Bulletin, February, 1960.

SPECIMEN 83 - EXTRA
(Continued)

Remarks - Specimen loaded at a crosshead speed of 0.5 ipm (not critical within range of 0.5 to 2.0 ipm); load sensed by load cell and continuously recorded on an oscillographic-type recorder with a frequency response of about 60 cps or higher; normally the load increases to a maximum value, then decreases at a relatively slow rate until a lower load is reached, at which time there is a very rapid change in the rate of unloading; maximum load denoted by P_m and load at which the rapid change in unloading begins is denoted by P_l; these loads are connected to maximum outer fiber stresses by means of a beam formula:

$$\sigma = \frac{3PL}{2wt^2}$$

where

G = maximum outer fiber stress, psi

P = load, pounds

L = distance between supports, (1.00) inches

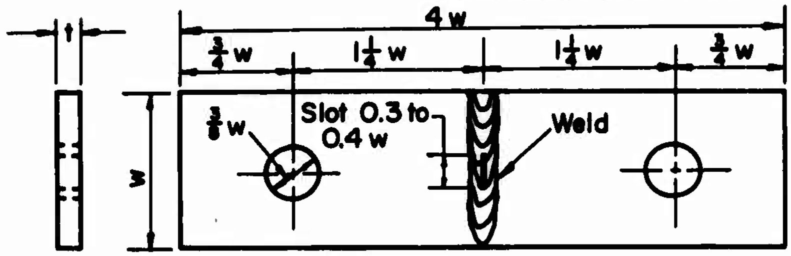
t = thickness of specimen (0.052 inch nominal)

w = width of specimen (0.700 inch nominal).

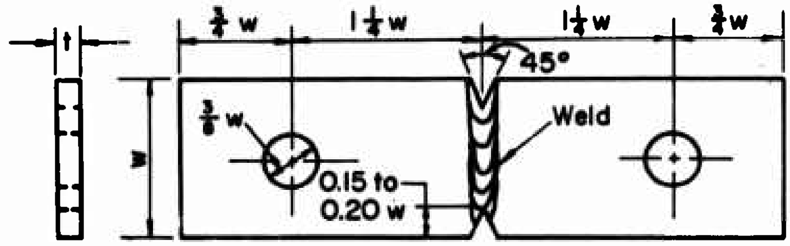
$\sigma_n - \sigma_l$ then is the instrumented bend-test parameter. This value correlates with K_c (critical-crack-toughness index) and other parameters from the center-notched tension test; specimen serves as a simple rapid screening test for crack-propagation resistance.

SPECIMENS 71 AND 72

CRACK-PROPAGATION SPECIMENS – CENTER-NOTCHED AND EDGE-NOTCHED TENSION



Center Notched Specimen



Edge - Notched Specimen

Test Section Width, W	Dimensions, inches: Thickness Range, Min	Thickness Range, Max	Minimum Length	Loading-Pin Diameter
1	0.022	0.063	4	3/8
2	0.044	0.125	8	3/4
3	0.067	0.188	12	1-1/8
4	0.088	0.250	16	1-1/2

Dimensions shown are recommended by ASTM for base-plate evaluation (see Reference): the dimensions used by polled organizations varied slightly; slot can be made by a variety of techniques such as electrical-discharge machining; however, the notch root radius is to be less than 0.001 inch; material cracks at the slot edges have been used; thick cracks have been formed by fatigue loading and by other techniques.

Materials Evaluated - All.

Purpose of Test - Developmental, crack susceptibility, crack propagation, and weldability.

Number of Specimens - Usually 3, varying from 2 to 5.

Nondestructive Inspection (in order of decreasing use) - Visual, radiographic, and penetrant.

Important Variables - Specimen geometry, weld quality, weld-inspection, testing equipment, specimen positioning, strain-rate control, instrumentation, test-temperature control, measurements, data processing, and data analysis.

Data Obtained - Ultimate strength, 0.2 per cent offset yield strength, elongation in 2 inches, fracture toughness, crack-extension force (G_c), critical-crack-toughness index (K_c), net fracture stress, unnotched to notched stress ratio.

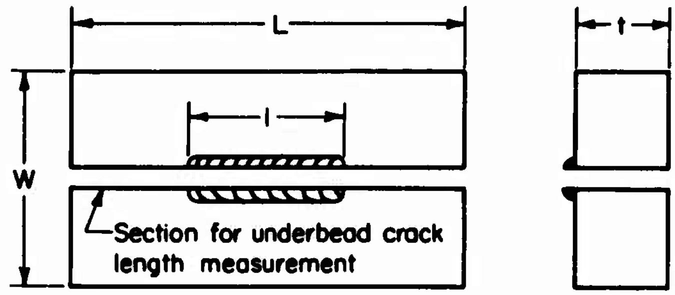
Specifications - None.

Reference - "Fracture Testing of High-Strength Sheet Materials", ASTM Committee on Fracture Testing of High-Strength Sheet Materials, ASTM Bulletin, January and February, 1960.

Remarks - This special committee of the ASTM was organized to review testing methods presently used and to recommend to the ASTM a standard method of evaluating high-strength materials with respect to their resistance to brittle fracture; the center-notched and edge-notched specimens have been recommended; however, all of the details regarding these specimens have not been finalized; procedures regarding specimen preparation, testing, and interpretation of results should be obtained from the reference cited.

SPECIMEN 80

UNDERBEAD-CRACKING SPECIMEN - LONGITUDINAL WELD



Dimensions, inches			
l	L	W	t
3	6	3	Plate t
1-1/4	3	2	Plate t

Smaller dimensions used in early research on underbead cracking. Bead usually deposited at room temperature but subzero as well as preheat temperature used.

Material Evaluated - Steels.

Purpose of Test - Crack susceptibility and, notably, underbead cracking tendencies.

Number of Specimens Tested - Usually 3.

Nondestructive Inspection (in order of decreasing use) - Visual, magnetic, penetrant, and X-ray.

Important Variables - Specimen geometry, weld quality, welding conditions, weld inspection, temperature of specimen when welded, and data analysis.

Data Obtained - Extent and type of cracking.

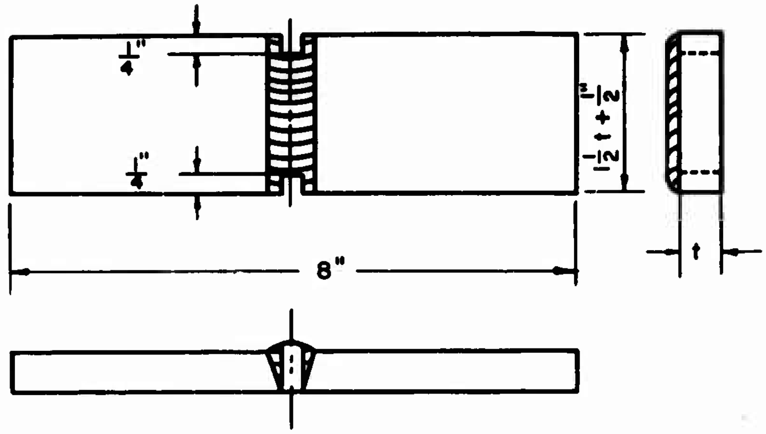
Specifications - None.

Reference - Stout, R. D., and Doty, W. D., Weldability of Steels, Welding Research Council, 1953, 225-229.

Remarks - Specimen developed to study underbead cracking. Length of cracking expressed as percentage of bead length. Although extent of cracking varies with individual specimens, average of ten tests reproducible within 10 per cent; average of 5 tests reproducible within 20 per cent.

SPECIMEN 77

NICK-BREAK-WELD-SOUNDNESS SPECIMEN



Other dimensions used occasionally. Dimensions not critical; tested at room temperature in air.

Materials Evaluated - Aluminum, magnesium, and steels.

Purpose of Test - Weld soundness and ductility.

Number of Specimens Tested - 2.

Nondestructive Inspection (in order of decreasing use) - Visual, penetrant, X-ray, and magnetic particle (where possible).

Important Variables - Weld quality, weld inspection, and data analysis.

Data Obtained - Fracture appearance, extent of porosity, cracking, and inclusions.

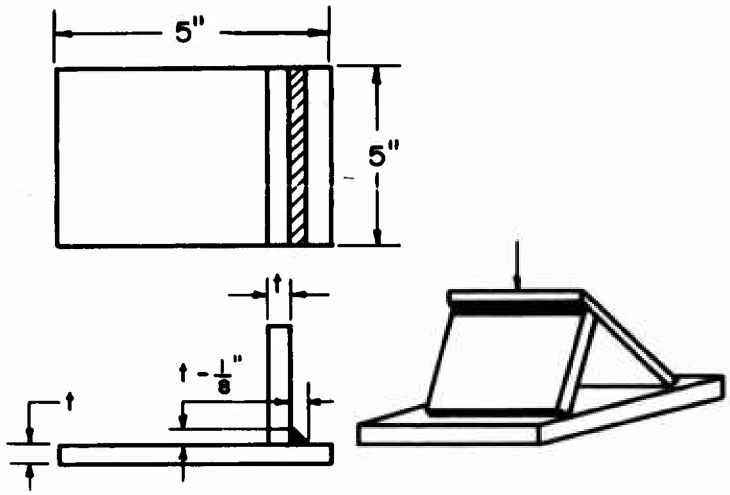
Specifications - API Std. 1104; ASME Sec. IX.

References - AWS Handbook, 4th Edition, Section 1, pp 9.8-9.9.

Remarks - Used principally as acceptance test for porosity and inclusion limitations. Specimen bent transversely at nicked cross section. Rate of loading not important.

SPECIMEN 78

FILLET WELD-SOUNDNESS SPECIMEN



Other dimensions used occasionally. Dimensions not critical; tested at room temperature in air.

Materials Evaluated - Aluminum, magnesium, and steels.

Purpose of Test - Weld soundness, root penetration, and ductility.

Number of Specimens Tested - 2.

Nondestructive Inspection (in order of decreasing use) - Visual, penetrant, magnetic (where possible), and X-ray.

Important Variables - Specimen geometry, weld quality, welding conditions, weld inspection, and data analysis.

Data Obtained - Extent of porosity, cracking, inclusions, and penetration.

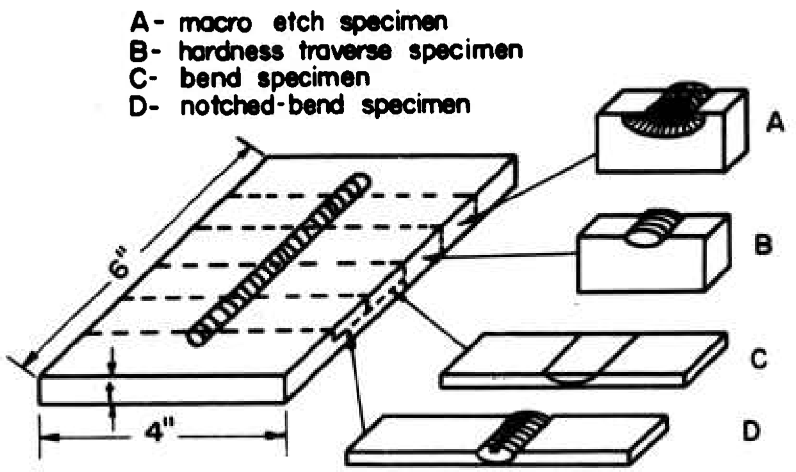
Specifications - ASME IX, AWS A40-42, MIL-E-8697.

Reference - AWS Handbooks, 4th Edition, Section 1, pp 9.18-9.19.

Remarks - Specimen broken apart by press or hammer blows. Fracture surfaces examined for porosity, inclusions, cracks, penetration, etc.

SPECIMEN 79

BEAD-ON-PLATE WELDABILITY SPECIMEN



Dimensions often changed to vary cooling rate.

Materials Evaluated - All.

Purpose of Test - Crack susceptibility; crack propagation; weld and HAZ hardness, bend ductility; study effects of welding conditions such as heat input, preheat, etc.; occasionally used for quality control.

Number of Specimens Tested - Usually a single specimen.

Nondestructive Inspection (in order of decreasing use) - Visual, X-ray, penetrant, and magnetic particle (where possible).

Important Variables - Specimen geometry (only as it affects weld cooling rate), weld quality, weld conditions, weld inspection, and data analysis.

Data Obtained - Hardness, soundness, microstructure, and elongation (in the case of bend specimens).

Specifications - None.

References - Henry, D. H., and Clausson, G. E., Welding Metallurgy, 2nd Edition, revised by Linnert, G. E., American Welding Society, pp 481-483.

Remarks - Simple but extremely useful test.

REQUIREMENTS OF A SATISFACTORY WELDMENT TEST

The requirements of a satisfactory test for evaluating weldments are: (1) direct correlation with actual fabrication or service, (2) high sensitivity to the effects of welding variables, (3) good reproducibility of results, (4) simplicity, (5) economy in the use of materials, (6) cheapness, and (7) applicability to all welding processes. No single specimen has yet been devised that will meet all of these requirements. So, test-specimen selection is, at best, a compromise. A thorough understanding of the information required from such a test is mandatory. Then, faithful execution of the testing procedure should provide a rational basis for the establishment of materials, procedures, and techniques, and, hopefully, a reasonable evaluation of expected service performance.

FUTURE NEEDS IN WELDMENT TESTING

The results of this survey point up the need for greater standardization of specimens for evaluating weldments both as to type of test and actual specimen dimensions. Specimen standardization was the objective of the ARTC Committee. However, only four specimens were suggested by the ARTC for standardization.

Complete standardization of test specimens of all types is very unlikely. However, considerably more standardization than now exists should be possible. Efforts should be directed toward that goal. Such an objective could be accomplished by an extensive program correlating test data with service performance as well as correlating similar data obtained by different specimens. Laboratory research programs should be initiated to supply much of the information regarding data correlation using various specimens. In this manner, questionable test specimens could be weeded out and the remaining specimens standardized as to configuration, dimensions, and procedures.

Duplication of effort because of a lack of standardization is costly. The investment in a long-range program of specimen standardization should ultimately result in substantial savings by reducing duplication.

APPENDIX A

QUESTIONNAIRES USED IN DMIC SURVEY

TABLE A-1. DMIC QUESTIONNAIRE NO. 1 – EVALUATION METHODS FOR ARC FUSION WELDS

What types of test are used?

1. Unnotched tension

    (a) Flat bar or sheet? Yes____ No____
    (b) Round bar? Yes____ No____

2. Notched tension

    (a) Flat bar or sheet? Yes____ No____
    (b) Round bar? Yes____ No____

3. Compression? Yes____ No____

4. Shear? Yes____ No____

5. Guided bend? Yes____ No____

6. Free bend? Yes____ No____

7. Notch bend? Yes____ No____

8. Impact?

    (a) Charpy vee-notch? Yes____ No____
    (b) Tensile impact? Yes____ No____
    (c) Drop weight? Yes____ No____
    (d) Explosion bulge? Yes____ No____
    (e) Other?

9. Ballistic impact? Yes____ No____

10. Fatigue?

    (a) Axial loading? Yes____ No____
    (b) Flexural? Yes____ No____
    (c) Rotational? Yes____ No____

11. Stress rupture? Yes____ No____

12. Creep?

    (a) Long time? Yes____ No____
    (b) Short time? Yes____ No____

13. Bulge? Yes____ No____

14. Crack susceptibility (circular patch, cruciform, etc.)?

    Yes____ No____

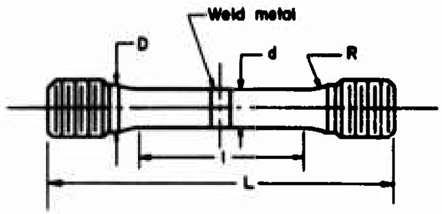
15. Crack propagation (NRL, NASA, etc.)? Yes____ No____

16. Prototype weldments?

    (a) Pressure vessels? Yes____ No____
    (b) Subscale models? Yes____ No____
    (c) Full-scale prototypes? Yes____ No____
    (d) Other

17. Others (please list).

TABLE A-2. SAMPLE SHEET OF QUESTIONNAIRE NO. 2 – TRANSVERSE-WELD TENSION SPECIMEN – ROUND



[illegible]	Appropriate Dimensions Below															[illegible]	[illegible]	[illegible]
	d	D	l	L	R													
1	.505	3/4	2-1/4	4-1/4	3/8											To	Air	
2	.357	1/2	1-3/4	3-1/2	3/8											To	Air	
3																		
4																		
5																		
6																		
7																		
8																		

I. Material Evaluated:
- A. Aluminum and magnesium alloys — 1 2 3 4 5 6 7 8
- B. Titanium and titanium alloys — 1 2 3 4 5 6 7 8
- C. Plain-carbon steels — 1 2 3 4 5 6 7 8
- D. Low-alloy, high-strength steels — 1 2 3 4 5 6 7 8
- E. Ultrahigh-strength steels — 1 2 3 4 5 6 7 8
- F. High-alloy steels — 1 2 3 4 5 6 7 8
- G. Refractory metals and their alloys — 1 2 3 4 5 6 7 8
- H. Beryllium — 1 2 3 4 5 6 7 8

II. Purpose of Test:
1. Developmental — 1 2 3 4 5 6 7 8
2. Production quality — 1 2 3 4 5 6 7 8
3. Strength
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8
4. Ductility
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8
5. Crack susceptibility
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8
6. Crack propagation
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8
7. Impact energy
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8
8. Fatigue
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8
9. Corrosion
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8
10. Other
   - a. Weldability — 1 2 3 4 5 6 7 8
   - b. Design allowables — 1 2 3 4 5 6 7 8

III. How many specimens are tested for:
(1) Weldability? 7
(2) Design allowables? 7

IV. What nondestructive inspection is used prior to testing?
Visual____ X-ray _X_ Magnetic ____ Penetrant____
Ultrasonic____ Eddy current____ None ____
Other ____ (state type).

V. What are the important variables in this test?
1. Specimen geometry? Yes _X_ No___
2. Weld quality? Yes _X_ No___
3. Weld inspection? Yes _X_ No___
4. Testing equipment? Yes ___ No _X_
5. Testing technique?
   - a. Specimen positioning? Yes _X_ No___
   - b. Strain rate control? Yes _X_ No___
   - c. Instrumentation? Yes ___ No _X_
   - d. Test temperature control? Yes ___ No _X_
   - e. Environment control? Yes ___ No _X_
   - f. Measurements? Yes _X_ No___
6. Data processing? Yes ___ No _X_
7. Data analysis? Yes _X_ No___
8. Other (state type) Yes ___ No _X_

VI. What data are obtained?
1. Ultimate tensile strength Yes _X_ No___
2. Yield strength
   - a. 0.1% offset Yes___ No___
   - b. 0.2% offset Yes _X_ No___
   - c. Other Yes___ No___
3. Fatigue strength Yes___ No___
   - a. Cycles to failure Yes___ No___
   - b. Endurance limit ___ Cycles
4. Stress to rupture Yes___ No___
   - a. In ___ hr
   - b. In ___ hr
5. Impact
   - a. Energy Yes___ No___
   - b. Lateral expansion Yes___ No___
   - c. Fracture appearance Yes___ No___
6. Elongation
   - a. In 1/2 in. Yes _X_ No___
   - b. In 1 in. Yes _X_ No___
   - c. In 2 in. Yes _X_ No___
7. Reduction in area Yes _X_ No___
8. Fracture toughness
   - a. Crack extension force (G_c) Yes___ No___
   - b. Critical-crack-toughness index (K_c) Yes___ No___
   - c. Net fracture stress Yes___ No___
   - d. Unnotched to notched stress ratio Yes___ No___
9. Degree of restraint Yes___ No___
10. Yes___ No___
11. Yes___ No___
12. Yes___ No___
13. Yes___ No___
14. Yes___ No___
15. Yes___ No___
16. Yes___ No___
17. Yes___ No___
18. Yes___ No___
19. Yes___ No___
20. Yes___ No___

VII. Are specimen preparation and testing procedures covered by Military, Technical Society, or Company Specifications? Yes _X_ No___
1. If yes, please list specification number(s).
   ASTM E-8

VIII. Are data presented in reports? Yes _X_ No___
1. Would these reports be available to DMIC? Yes _X_ No___
2. To AIA? Yes _X_ No___
   - a. If yes, please list reports.
     ABC Company Progress Report 3-60, June 1960
     ABC Company Final Report, Project TJ 37-6, April 1959

APPENDIX B

ORGANIZATIONS CONTRIBUTING TO SURVEY

TABLE B-1. ORGANIZATIONS CONTRIBUTING TO DMIC SURVEY

Bureau of Ships Department of the Navy Washington, D. C.	General Dynamics Corporation Electric Boat Division Groton, Connecticut
George C. Marshall Space Flight Center National Aeronautics and Space Administration Huntsville, Alabama	Allis-Chalmers Manufacturing Company Milwaukee, Wisconsin
Naval Air Material Center Aeronautical Materials Laboratory Department of the Navy Philadelphia, Pennsylvania	Alco Products, Inc. Schenectady, New York
Engineer Research and Development Laboratories United States Army Fort Belvoir, Virginia	A. O. Smith Corporation Milwaukee, Wisconsin
Jet Propulsion Laboratory Pasadena, California	Babcock and Wilcox Company Atomic Energy Division Lynchburg, Virginia
Wright Air Development Division United States Air Force Wright-Patterson Air Force Base, Ohio	Baldwin-Lima-Hamilton Corporation Standard Steel Works Burnham, Mifflin County, Pennsylvania
Ordnance Tank-Automotive Command United States Army Detroit, Michigan	The Budd Company Philadelphia, Pennsylvania
Frankford Arsenal United States Army Ordnance Philadelphia, Pennsylvania	Chicago Bridge and Iron Company Chicago, Illinois
Watertown Arsenal Watertown, Massachusetts	United States Steel Corporation Consolidated Western Steel Division Los Angeles, California
Crucible Steel Company Pittsburgh, Pennsylvania	Ingalls Iron Works Birmingham, Alabama
International Nickel Company, Inc. Bayonne, New Jersey	Excelco Development, Inc. Silver Creek, New Jersey
Ladish Steel Company Cudahy, Wisconsin	Kaiser Industries Kaiser Fleetwings Division Bristol, Pennsylvania
Vanadium-Alloys Steel Company Latrobe, Pennsylvania	Graver Tank and Manufacturing Company East Chicago, Indiana
	Thompson Ramo Wooldridge, Inc. Cleveland, Ohio

TABLE B-1. (Continued)

Air Reduction Company Murray Hill, New Jersey	Standard Oil Company Whiting, Indiana
Harnischfeger Corporation Milwaukee 7, Wisconsin	Lehigh University Bethlehem, Pennsylvania
Union Carbide Corporation Linde Company Newark, New Jersey	

TABLE B-2. ORGANIZATIONS CONTRIBUTING TO ARTC SURVEY

The Bendix Corporation Bendix Products Division South Bend, Indiana	Grumman Aircraft Bethpage, New York
Boeing Airplane Company Wichita Division Wichita, Kansas	Lockheed Aircraft Corporation California Division Sunnyvale, California
Boeing Airplane Company Seattle, Washington	Lockheed Aircraft Corporation Georgia Division Marietta, Georgia
Chance Vought Aircraft, Inc. Dallas, Texas	The Martin Company Baltimore, Maryland
Convair Fort Worth, Texas	McDonnell Aircraft Corporation St. Louis, Missouri
Convair Pomona, California	North American Aviation Inc. Columbus Division Columbus, Ohio
Convair San Diego, California	North American Aviation Inc. Los Angeles Division Los Angeles, California
Douglas Aircraft Company Santa Monica, California	Northrup Corporation Norair Division Hawthorne, California
Fairchild Engine and Airplane Corporation Fairchild Aircraft and Missile Division Hagerstown, Maryland	Republic Aviation Corporation Farmingdale, New York
General Electric Company Missile and Space Vehicle Department Philadelphia, Pennsylvania	United Aircraft Corporation Sikorsky Aircraft Division Stratford, Connecticut
Goodyear Tire and Rubber Company Aeromechanics Research and Development Akron, Ohio	

LIST OF DMIC TECHNICAL REPORTS ISSUED
DEFENSE METALS INFORMATION CENTER

Battelle Memorial Institute

Columbus 1, Ohio

Copies of the technical reports listed below may be obtained from DMIC at no cost by Government agencies, and by Government contractors, subcontractors, and their suppliers. Others may obtain copies from the Office of Technical Services, Department of Commerce, Washington 25, D. C. See PB numbers and prices in parentheses.

DMIC Report Number	Title
46D	Department of Defense Titanium Sheet-Rolling Program - Uniform Testing Procedure for Sheet Materials, September 12, 1958 (PB 121649 $1.25)
46E	Department of Defense Titanium Sheet-Rolling Program - Thermal Stability of the Titanium Sheet-Rolling-Program Alloys, November 25, 1958 (PB 151061 $1.25)
46F	Department of Defense Titanium Sheet-Rolling Program Status Report No. 4, March 20, 1959 (PB 151065 $2.25)
46G	Department of Defense Titanium Sheet-Rolling Program - Time-Temperature-Transformation Diagrams of the Titanium Sheet-Rolling Program Alloys, October 19, 1959 (PB 151075 $2.25)
46H	Department of Defense Titanium Sheet-Rolling Program, Status Report No. 5, June 1, 1960 (PB 151087 $2.00)
46I	Statistical Analysis of Tensile Properties of Heat-Treated Ti-4Al-3Mo-1V Sheet, September 16, 1960 (PB 151095 $1.25)
46J	Statistical Analysis of Tensile Properties of Heat-Treated Ti-4Al-3Mo-1V and Ti-2.5Al-16V Sheet (AD 259284 $1.25)
106	Beryllium for Structural Applications, August 15, 1958 (PB 121648 $3.00)
107	Tensile Properties of Titanium Alloys at Low Temperature, January 15, 1959 (PB 151062 $1.25)
108	Welding and Brazing of Molybdenum, March 1, 1959 (PB 151063 $1.25)
109	Coatings for Protecting Molybdenum From Oxidation at Elevated Temperature, March 6, 1959 (PB 151064 $1.25)
110	The All-Beta Titanium Alloy (Ti-13V-11Cr-3Al), April 17, 1959 (PB 151066 $3.00)
111	The Physical Metallurgy of Precipitation-Hardenable Stainless Steels, April 20, 1959 (PB 151067 $2.00)
112	Physical and Mechanical Properties of Nine Commercial Precipitation-Hardenable Stainless Steels, May 1, 1959 (PB 151068 $3.25)
113	Properties of Certain Cold-Rolled Austenitic Stainless Sheet Steels, May 15, 1959 (PB 151069 $1.75)
114	Ductile-Brittle Transition in the Refractory Metals, June 25, 1959 (PB 151070 $2.00)
115	The Fabrication of Tungsten, August 14, 1959 (PB 151071 $1.75)
116R	Design Information on 5Cr-Mo-V Alloy Steels (H-11 and 5Cr-Mo-V Aircraft Steel) for Aircraft and Missiles (Revised), September 30, 1960 (PB 151072-R $1.50)
117	Titanium Alloys for High-Temperature Use Strengthened by Fibers or Dispersed Particles, August 31, 1959 (PB 151073 $2.00)
118	Welding of High-Strength Steels for Aircraft and Missile Applications, October 12, 1959 (PB 151074 $2.25)
119	Heat Treatment of High-Strength Steels for Aircraft Applications, November 27, 1959 (PB 151076 $2.50)
120	A Review of Certain Ferrous Castings Applications in Aircraft and Missiles, December 18, 1959 (PB 151077 $1.50)
121	Methods for Conducting Short-Time Tensile, Creep, and Creep-Rupture Tests Under Conditions of Rapid Heating, December 20, 1959 (PB 151078 $1.25)
122	The Welding of Titanium and Titanium Alloys, December 31, 1959 (PB 151079 $1.75)
123	Oxidation Behavior and Protective Coatings for Columbium and Columbium-Base Alloys, January 15, 1960 (PB 151080 $2.25)
124	Current Tests for Evaluating Fracture Toughness of Sheet Metals at High Strength Levels, January 28, 1960 (PB 151081 $2.00)
125	Physical and Mechanical Properties of Columbium and Columbium-Base Alloys, February 22, 1960 (PB 151082 $1.75)
126	Structural Damage in Thermally Cycled René 41 and Astroloy Sheet Materials, February 29, 1960 (PB 151083 $0.75)
127	Physical and Mechanical Properties of Tungsten and Tungsten-Base Alloys, March 15, 1960 (PB 151084 $1.75)
128	A Summary of Comparative Properties of Air-Melted and Vacuum-Melted Steels and Superalloys, March 28, 1960 (PB 151085 $2.75)
129	Physical Properties of Some Nickel-Base Alloys, May 20, 1960 (PB 151086 $2.75)
130	Selected Short-Time Tensile and Creep Data Obtained Under Conditions of Rapid Heating, June 17, 1960 (PB 151088 $2.25)
131	New Developments of the Welding of Metals, June 24, 1960 (PB 151089 $1.25)
132	Design Information on Nickel-Base Alloys for Aircraft and Missiles, July 20, 1960 (PB 151090 $3.00)
133	Tantalum and Tantalum Alloys, July 25, 1960 (PB 151091 $5.00)
134	Strain Aging of Refractory Metals, August 12, 1960 (PB 151092 $1.75)
135	Design Information on PH 15-7 Mo Stainless Steel for Aircraft and Missiles, August 22, 1960 (PB 151093 $1.25)

DMIC Report Number	Title
136A	The Effects of Alloying Elements in Titanium, Volume A. Constitution, September 15, 1960 (PB 151094 $3.50)
136B	The Effects of Alloying Elements in Titanium, Volume B. Physical and Chemical Properties, Deformation and Transformation Characteristics, May 29, 1961 (AD 260226 $3.00)
137	Design Information on 17-7 PH Stainless Steels for Aircraft and Missiles, September 23, 1960 (PB 151096 $1.00)
138	Availability and Mechanical Properties of High-Strength Steel Extrusions, October 26, 1960 (PB 151097 $1.75)
139	Melting and Casting of the Refractory Metals Molybdenum, Columbium, Tantalum, and Tungsten, November 18, 1960 (PB 151098 $1.00)
140	Physical and Mechanical Properties of Commercial Molybdenum-Base Alloys, November 30, 1960 (PB 151099 $3.00)
141	Titanium-Alloy Forgings, December 19, 1960 (PB 151100 $2.25)
142	Environmental Factors Influencing Metals Applications in Space Vehicles, December 27, 1960 (PB 151101 $1.25)
143	High-Strength-Steel Forgings, January 5, 1961 (PB 151102 $1.75)
144	Stress-Corrosion Cracking - A Nontechnical Introduction to the Problem, January 6, 1961 (PB 151103 $0.75)
145	Design Information on Titanium Alloys for Aircraft and Missiles, January 10, 1961 (PB 151104 $2.25)
146	Manual for Beryllium Prospectors, January 18, 1961 (PB 151105 $1.00)
147	The Factors Influencing the Fracture Characteristics of High-Strength Steel, February 6, 1961 (PB 151106 $1.25)
148	Review of Current Data on the Tensile Properties of Metals at Very Low Temperatures, February 14, 1961 (PB 151107 $2.00)
149	Brazing for High Temperature Service, February 21, 1961 (PB 151108 $1.00)
150	A Review of Bending Methods for Stainless Steel Tubing, March 2, 1961 (PB 151109 $1.50)
151	Environmental and Metallurgical Factors of Stress-Corrosion Cracking in High-Strength Steels, April 14, 1961 (PB 151110 $0.75)
152	Binary and Ternary Phase Diagrams of Columbium, Molybdenum, Tantalum, and Tungsten, April 28, 1961 (AD 257739 $3.50)
153	Physical Metallurgy of Nickel-Base Superalloys, May 5, 1961 (AD 258041 $1.25)
154	Evolution of Ultrahigh-Strength, Hardenable Steels for Solid-Propellant Rocket-Motor Cases, May 25, 1961 (AD 257976 $1.25)
155	Oxidation of Tungsten, July 17, 1961 (AD 263598 $3.00)
156	Design Information on AM-350 Stainless Steel for Aircraft and Missiles, July 28, 1961 (AD 262407 $1.50)
157	A Summary of the Theory of Fracture in Metals, August 7, 1961
158	Stress-Corrosion Cracking of High-Strength Stainless Steels in Atmospheric Environments, September 15, 1961
159	Gas-Pressure Bonding, September 25, 1961
160	Introduction to Metals for Elevated-Temperature Use, October 27, 1961
161	Status Report No. 1 on Department of Defense Refractory Metals Sheet-Rolling Program, November 2, 1961
162	Coatings for the Protection of Refractory Metals From Oxidation, November 24, 1961
163	Control of Dimensions in High-Strength Heat-Treated Steel Parts, November 29, 1961
164	Semiaustenitic Precipitation-Hardenable Stainless Steels, December 6, 1961

Battelle Memorial Institute, Defense Metals Information Center, Columbus, Ohio. METHODS OF EVALUATING WELDED JOINTS, by M. D. Randall, R. E. Monroe, and P. J. Rieppel. December 28, 1961. [78] pp incl. illus., tables. (DMIC Report 165) [AF 33(616)-7747] Unclassified report

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2. Welded Joints-Test Methods

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